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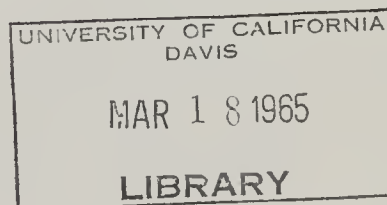


THE RESOURCES AGENCY OF CALIFORNIA
Department of Water Resources

BULLETIN No. 134-62

SALINE
WATER CONVERSION ACTIVITIES
IN CALIFORNIA

AUGUST 1963



HUGO FISHER
Administrator
The Resources Agency of California

EDMUND G. BROWN
Governor
State of California

WILLIAM E. WARNE
Director
Department of Water Resources





ONE MILLION GALLONS PER DAY SEA WATER CONVERSION PLANT
POINT LOMA, SAN DIEGO, CALIFORNIA

State of California
THE RESOURCES AGENCY OF CALIFORNIA
Department of Water Resources

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TABLE OF CONTENTS

| | <u>Page</u> |
|---|-------------|
| LETTER OF TRANSMITTAL | vii |
| ORGANIZATION, DEPARTMENT OF WATER RESOURCES | viii |
| PART I. CONVERSION ACTIVITIES OF THE DEPARTMENT OF WATER RESOURCES | |
| INTRODUCTION | 1 |
| GENERAL PROGRAM | 2 |
| INVESTIGATIONS | 3 |
| The San Diego Demonstration Plant | 4 |
| San Joaquin Valley Drain | 8 |
| Salton Sea State Park | 12 |
| Economics of Conversion | 20 |
| Electrodialysis | 20 |
| Distillation | 23 |
| Nuclear Energy | 25 |
| Solar Energy | 27 |
| Survey of Brackish Water Areas | 27 |
| PART II. OTHER CONVERSION ACTIVITIES WITHIN CALIFORNIA | |
| A. UNIVERSITY OF CALIFORNIA | |
| INTRODUCTION | 35 |
| REPORTS | 36 |
| PROJECTS | 38 |
| Electrodialysis | 38 |
| Carryover Studies | 38 |
| Scale Studies | 38 |

| | <u>Page</u> |
|--|-------------|
| Ion Exchange | 39 |
| Direct Contact Heat Transfer | 39 |
| Freeze-Separation | 39 |
| Thermodynamic Studies | 39 |
| Solar Distillation Studies | 39 |
| Multiple Effect Rotating Still | 39 |
| Capillary Control of Vapor Transfer Gap | 40 |
| Pilot Plant Development | 40 |
| Demineralization by Means of a Semipermeable Membrane | 40 |
| Techniques of Optimization | 40 |
| Transport Phenomena Near a Liquid Vapor Interface | 41 |
| Experimental Heat Transfer Studies | 41 |
| Waste Water Reclamation Biological Systems | 41 |
| Corrosion Studies | 41 |
| B. OTHER AGENCIES | |
| COALINGA | 42 |
| OFFICE OF SALINE WATER | 44 |
| Demonstration Plant | 44 |
| Research and Development | 47 |
| Aerojet-General Corporation | 48 |
| Bechtel Corporation | 48 |
| FMC Corporation | 49 |

| | <u>Page</u> |
|--|-------------|
| Ford Motor Company | 50 |
| General Dynamics Corporation . . . | 51 |
| Leslie Salt Company | 52 |
| Narmco Research & Development . . . | 52 |
| Stanford Research Institute . . . | 53 |
| University of California | 54 |
| Western Independent Research Laboratories | 55 |
| UNITED STATES NAVY | 55 |
| PRIVATE COMPANIES | 56 |
| Pacific Gas & Electric Company | 57 |
| Southern California Edison Company . . | 58 |
| North American Aviation | 58 |
| Havens Industries | 60 |

TABLES

Table No.

| | |
|--|----|
| 1. San Joaquin Valley Drainage Water - Quality and Quantity | 9 |
| 2. Typical Water Quality of San Joaquin Valley Drainage Water | 11 |
| 3. Composition of Salton Sea and Pacific Ocean Water | 15 |
| 4. Estimated Capital Cost of Conversion Plants at Salton Sea State Park | 17 |
| 5. Current Sea and Brackish Water Conversion Cost Estimates | 21 |

| | <u>Page</u> |
|--|-------------|
| 6. Basic Data on Areas in Southern California for Possible Sites for Saline Water Conversion Plants | 29 |
| 7. Reports Issued during 1962 by University of California Water Resources Center, Sea Water Conversion Program | 37 |
| 8. Report of Chemical Analysis of Coalinga Water . . | 43 |
| 9. Office of Saline Water Research and Development Progress Reports | 45 |

Figure No.

FIGURES

| | |
|--|----|
| 1. Schematic Flow Diagram of the Multistage Flash Evaporation Process at San Diego, California . . | 6 |
| 2. Location of Proposed Conversion Plants at Salton Sea | 16 |

APPENDIXES

| | |
|--|-----|
| APPENDIX A - Conversion Activities Outside California . . | A-1 |
| APPENDIX B - Application of Solar Energy to Conversion in California | B-1 |
| APPENDIX C - Bibliography | C-1 |

EDMUND G. BROWN
GOVERNOR OF
CALIFORNIA

HUGO FISHER
ADMINISTRATOR
RESOURCES AGENCY

ADDRESS REPLY TO
P. O. Box 388
Sacramento 2, Calif.



THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES

1120 N STREET, SACRAMENTO

June 17, 1963

Honorable Edmund G. Brown, Governor
and Members of the Legislature of the
State of California

Gentlemen:

I have the honor to transmit herewith Bulletin
No. 134-62, of the State Department of Water Resources,
entitled "Saline Water Conversion Activities in California."

The report finds that, in general, no single purpose
conversion process can now compete with the cost of large-
scale development of natural sources of water in California.
Under certain conditions conversion plants, combined with
power generation, may become economically attractive within
the foreseeable future.

The economic potential of the conversion of brack-
ish water and waste water renovation is comparatively more
promising than conversion of more saline sources.

The research and development work now in progress
by other agencies and private enterprise within the State
on conversion of sea water, brackish water, and waste water
are described in this bulletin. Activities in the field
outside California are also briefly described.

Sincerely yours,

Director

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES

EDMUND G. BROWN, Governor
HUGO FISHER, Administrator, The Resources Agency of California
WILLIAM E. WARNE, Director, Department of Water Resources
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DIVISION OF RESOURCES PLANNING

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The preparation of this report was
conducted under the direction of:

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BY

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PART I. CONVERSION ACTIVITIES OF THE DEPARTMENT OF WATER RESOURCES

INTRODUCTION

The primary objective of the department's program in conversion is its application to the development of water resources that are otherwise unsuitable for the intended application. Such waters include sea and brackish water, which normally contain primarily inorganic contaminants, and treated waste waters which contain both organic and inorganic contaminants.

When the dissolved contaminants are removed from such waters, they may then be considered as alternative sources of supply. The actual use may be for domestic, industrial, or agricultural applications, or for replenishment of ground water, depending on the treatment provided and dissolved contaminants removed.

For any given application for the conversion of water, the matter of economics is of overriding concern, since a choice may usually be made from among a number of alternative water supplies. However, economics is closely related to techniques; therefore, both technological advancements and the related economics are of prime interest to the department.

Part II of the bulletin discusses conversion activities within California by other agencies and private companies. Appendix A describes some of the highlights of conversion throughout the world.

GENERAL PROGRAM

The application of conversion, whenever feasible, to the further development of the State's water resources and the advancement of the technology and economics of conversion are the chief objectives in this program of the department.

Currently, consideration is being given to the application of conversion techniques as part of the overall study of the San Joaquin Valley Drainage investigation.

Increased attention is being given to the removal of organic contaminants from waste water. The particular contaminants are those that are not degraded by the usual waste water treatment plants. Such materials are termed refractory.

Consideration is being given to improvement in quality of ground and surface water supplies by removal of dissolved materials in areas within the State where total dissolved solids are above 1,000 ppm or appear to be increasing as more intensive use is made of the water supplies. It is also planned to evaluate the potential of conversion in the long-range planning of the department. Because such plans extend for a long time into the future, it is prudent to evaluate the role conversion may play in such plans.

Activities of the department in conversion in carrying out the above-mentioned objectives and discharging its responsibility as technical advisor to the Legislature and to water agencies, include the following:

1. To keep thoroughly informed on existing and potential conversion processes and advanced waste water renovation processes.

2. To associate and cooperate with other public and private agencies involved in problems of the removal of dissolved materials from water.

3. To collect and analyze technical and cost data on conversion and renovation plants now in operation or being constructed, including demonstration and pilot plants.

4. To investigate and plan in specific areas for the application of processes capable of removing contaminants from water sources.

5. To advise communities on the applicability of conversion processes to their water supply problems.

6. To keep the public informed on conversion applications.

7. To evaluate potential demonstration or experimental conversion plant installations either as cooperative projects with other public agencies, or independently.

INVESTIGATIONS

Studies of the application of conversion as an alternative water supply or quality improvement were made for the

Salton Sea area and in the San Joaquin Valley. The major effort the previous year was with the construction of the San Diego sea water conversion plant. This effort was continued during the early part of 1962, at which time the performance test was being followed closely. Also, the department's engineer remained at the site to observe the initial operation of the plant during the first half of the year.

The details of the several investigations undertaken in conversion by the department are discussed in this section of the bulletin. In addition, indications of feasibility of application under various conditions and situations are discussed.

The San Diego Demonstration Plant

The department has cooperated both technically and financially with the Office of Saline Water (OSW) on the construction of the one million gallons per day multistage flash evaporator demonstration plant. The plant is located on Point Loma near San Diego.

During the construction phase in 1961 the department devoted considerable effort to the plant. In addition to having a resident engineer at the site during the construction, the department checked the construction drawings and calculations of the contractor and made appropriate comments thereon to the OSW.

After the plant construction was completed in November 1961, the construction contractor devoted the early part of 1962

to the operation of the plant. During this period the mechanical features were checked under operating conditions and the plant was prepared for the performance test required as part of the construction contract. The department participated in these activities and kept an engineer at the site during the first half of 1962 to observe this performance.

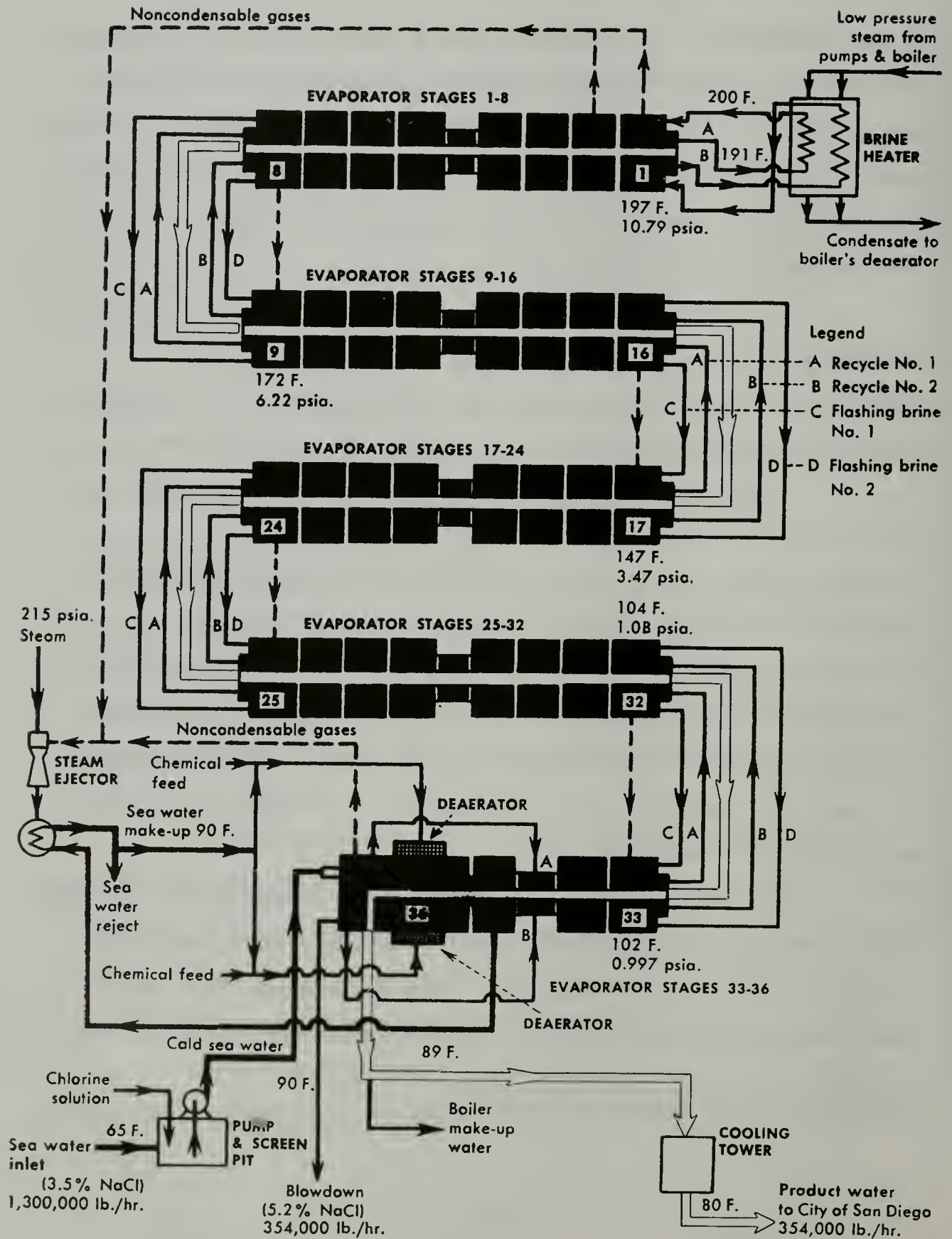
The operation and design of the plant has been previously described (1,2,3,4).* A brief description is included in this bulletin. In addition, a schematic flow diagram of the process, with some typical operating conditions is shown in Figure 1.

In this process, the sea water is pumped through the tubes of the 36th and 35th evaporator stages and the air ejector condenser before being introduced into the deaerator, which is connected to the shellside of the 36th stage. The 36th stage is the lowest pressure and temperature stage. Before the sea water is introduced into the deaerator, the excess which is required for cooling, is discharged back into the ocean. The remainder is treated with chemicals for scale prevention before it is introduced into the deaerator.

The deaerated sea water serves as a make-up to the plant. It is mixed in the shellside of the 36th stage with the brine before the two streams are pumped from the stage. The excess brine is also pumped from this stage and returned to the ocean.

*Refers to Bibliography - Appendix C.

FIGURE 1
SCHEMATIC FLOW DIAGRAM OF THE
MULTISTAGE FLASH EVAPORATION PROCESS
AT SAN DIEGO, CALIFORNIA
(TYPICAL OPERATING CONDITIONS)



The combined brine and make-up constitute the recycle stream that is pumped through the tubes of the evaporators from stage 34 to stage 1 and the brine heater.

In the brine heater steam is used to heat the brine to the desired temperature. The heated brine is then introduced into the shellside of the first stage, which is the highest temperature stage. The flashing process starts in this stage. The brine then flows from stage to stage. Each succeeding stage is maintained at a lower pressure than the previous stage. A quantity of vapor sufficient to cool the brine to the temperature in equilibrium with the stage pressure is flashed in each stage. When the brine reaches the 36th stage, as previously described, it is either recycled through the evaporators or discharged into the ocean.

The condensate which is condensed in each stage is caught in a trough and flows through the evaporators until it reaches the 36th stage. It also flashes in each stage sufficiently to cool it to the temperature in equilibrium with the pressure in the stage. It is pumped from the 36th stage to a cooling tower where the product is cooled to 80°F. before it is delivered to San Diego's treatment and pumping facility.

Additional information about the operation of this plant by the Office of Saline Water is given in Part II of this bulletin.

San Joaquin Valley Drain

The need for disposal of agricultural drainage water in major portions of the San Joaquin Valley through the San Joaquin Valley Drainage Facilities, is under intensive study by the department. The economic potential of the partial removal of dissolved material from the drainage water by electrodialysis, biological means, or other processes, is under study as part of this investigation (5).

Because of the diverse nature of the material expected in the drainage water, a study is planned to evaluate the several conversion processes and to define areas where additional information may be required before conversion cost estimates can be finalized.

Preliminary estimates of conversion utilizing the electrodialysis process, based on both current technology and upon projected technological improvements by the time the drainage canal is in operation, have been made in an exploratory manner.

The quantity of water that will require disposal by decade has previously been reported (5). Table 1 gives the quantity by decade of drainage water that will require disposal; also included in the table is the approximate average total dissolved solids of the drainage effluent. As can be seen, a substantial amount of water would require treatment if conversion were to be used. The total dissolved solids are fairly high for

TABLE 1
SAN JOAQUIN VALLEY DRAINAGE WATER
QUALITY AND QUANTITY

| <u>Decade</u> | <u>Acre-feet per Decade, Thousands</u> | <u>Approximate Total Dissolved Solids, ppm^{1/}</u> |
|-------------------------|--|---|
| 1960-1969 | 2,281 | 8,200 |
| 1970-1979 | 2,576 | 4,700 |
| 1980-1989 | 2,591 | 5,300 |
| 1990-1999 ^{2/} | 2,483 | 4,400 |
| 2000-2009 ^{2/} | 1,979 | 3,500 |
| 2010-2019 ^{2/} | 1,488 | 3,100 |

^{1/}Parts per million parts of water.

^{2/}Based on estimated irrigated acreage for the average of the 1990-1999 decade.

the initial ten-year period. However, the total dissolved solids falls rapidly and for a considerable number of years will average about 4,500 ppm of salts.

There are some tile drain effluents presently operating in the San Joaquin Valley. Based on these effluents, a typical analysis was developed for the exploratory study. The analysis is given in Table 2. With the exception of the boron, the composition is not unusual for a brackish water containing this amount of total dissolved solids. As the total salinity is either increased or decreased, there will be a proportionate change in the ions present. More complete analyses are being developed from which a more detailed economic analysis of conversion of the drainage water by the electrodialysis process will be made during the coming year.

With the present technology of the electrodialysis process, it is estimated that the salinity can be reduced from about 6,500 ppm to 1,600 ppm, thereby making the effluent suitable for reuse by agriculture for \$195 per acre-foot. This cost includes amortization, operation, and maintenance costs. The operating and maintenance costs amount to over 80 percent of the total. The cost of reducing the salinity to potable water is about \$235 per acre-foot.

As shown in Table 1, it is anticipated that the salinity will ultimately be reduced to 3,100 ppm. The costs of making this water suitable for agricultural reuse will be about \$105 per acre-foot, based on current technology.

TABLE 2

TYPICAL WATER QUALITY OF SAN JOAQUIN VALLEY DRAINAGE WATER
(Based on tile drain effluents)

| <u>Constituent</u> | <u>Amount, ppm^{1/}</u> |
|---------------------------------|---------------------------------|
| Calcium (Ca) | 320 |
| Magnesium (Mg) | 250 |
| Sodium (Na) | 1,800 |
| Potassium (K) | 4 |
| Bicarbonate (HCO ₃) | 250 |
| Sulfate (SO ₄) | 2,800 |
| Chloride (Cl) | 1,100 |
| Boron (B) | 24 |
| Silica (SiO ₂) | 32 |
| Nitrate | 6 |

^{1/}Parts per million parts of water

It is anticipated that technological improvements in the electrodialysis process within the next few years will reduce the conversion costs cited above by a factor of two. Consequently, by the time the drainage canal is in operation, or shortly thereafter, it may be possible to remove solids from the drainage water, based on the initial condition of salinity for about \$100 per acre-foot, and based on the equilibrium salinity for about \$50 per acre-foot. Since the salinity rapidly decreases during the second decade, it can be anticipated that further reduction in the costs of conversion will be possible by the time the salinity reaches the 4,500-5,000 range. Also, it is expected it will be possible to operate electrodialysis stacks with considerably higher salinity concentration in the brine discharge than is currently practiced. This would permit a reduction of the volume of highly saline water to a level that could be more easily disposed of either by ponding or by pumping by pipeline to the ocean. Additional work is planned during the next year on the application of techniques of conversion, not only electrodialysis, but other potential conversion processes, to the disposal of the agricultural drainage water.

Salton Sea State Park

At the request of the Department of Parks and Recreation, the department undertook a study of the alternative water supplies available to the Salton Creek area of the Salton Sea State Park.

A report by the department titled "Investigation of Sources of Water Supply for Salton Sea State Park" was made to the Department of Parks and Recreation.

Conversion of water of the Salton Sea was considered as one of four alternative sources. The four plans and the estimated water costs from each are as follows:

| <u>Plan</u> | <u>Cost, \$/acre-foot</u> |
|--|---------------------------|
| Salton Sea Water District (area method) | 355 |
| State-owned well | 450 |
| Coachella Valley Co. Water District | 485 |
| Salton Sea Water Conversion | 580 |

As can be seen, the estimated cost of water from the newly-formed Salton Sea Water District was substantially less than the other three alternatives. The Department of Parks and Recreation has requested funds for fiscal year 1963-64 to obtain water for the park from the Salton Sea Water District.

Actually, conversion compared rather favorably with the other two alternatives. The unusual water demand curve at the park placed the state-owned well and the saline water conversion alternative at a distinct disadvantage because of their higher capital cost. This particular study was of interest because the conversion of water from the Salton Sea probably offers as great a challenge to a conversion process as any saline water source in

the State. It is considered encouraging that converted water compared as favorably as it did with the other alternatives. The composition of this highly saline water is given in Table 3. For comparison, the composition of the Pacific Ocean is also given in Table 3.

Because it was intended to use the water at several locations along the east side of the Salton Sea, three 100,000 gpd multistage flash distillation plants were assumed for the analysis. One each would be located at Mecca Beach, Salt Creek Beach, and Bombay Beach. The distribution system to convey and regulate the converted water would require a 250,000 gallon tank and a 15-horsepower booster pumping plant at each of the three park developments. Also, about 700 feet of 4-inch diameter pipeline would be needed at each development between the conversion plants and the tanks. The general locations of the facilities are shown in Figure 2.

The total capital investment required is estimated to be \$944,000. This cost breakdown is shown in Table 4. The life of mechanical items of the conversion plant is estimated to be 25 years and, therefore, require replacement during the amortization period of fifty years. The capital cost of the other items of the conversion plant were amortized over a fifty-year period in order to be compatible with the estimates made for the other alternative supplies.

TABLE 3.

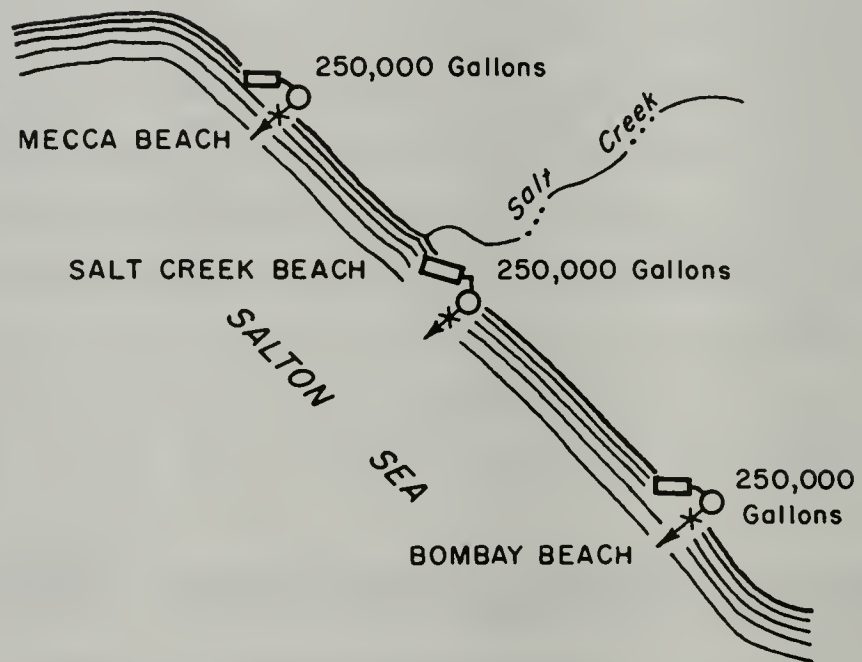
COMPOSITION OF SALTON SEA AND PACIFIC OCEAN WATER
 (Values expressed in parts per million parts of water)

| <u>Constituent</u> | <u>Salton Sea^{1/}</u> | | <u>Pacific Ocean^{2/}</u> |
|---------------------------------|--------------------------------|-------------------|-----------------------------------|
| | <u>May 1961</u> | <u>Sept. 1961</u> | <u>Range</u> |
| Sodium (Na) | 10,000 | 9,680 | 10,052 - 10,444 |
| Magnesium (Mg) | 967 | 1,118 | 1,211 - 1,259 |
| Calcium (Ca) | 800 | 790 | 381 - 396 |
| Potassium (K) | 172 | 140 | 362 - 376 |
| Chloride (Cl) | 14,300 | 14,600 | 18,074 - 18,779 |
| Sulfate (SO ₄) | 7,320 | 7,349 | 2,522 - 2,620 |
| Bicarbonate (HCO ₃) | 195 | 187 | 133 - 138 |
| Fluoride (F) | 3 | 3 | 1 - 1 |
| Boron (B) | 7.2 | 7.5 | 4.4 - 4.6 |
| Bromide (Br) | - | - | 62 - 64 |

^{1/} Analysis by Department of Water Resources - sampled at Salton Sea State Park.

^{2/} Calculated from chlorinity measurements of samples taken at Scripps Institution of Oceanography pier. 48-year average.

FIGURE 2
 LOCATION OF PROPOSED
 SALINE WATER CONVERSION PLANTS
 (SALTON SEA STATE PARK)



LEGEND

- | | |
|------------|--------------------|
| — PIPELINE | ○ RESERVOIR |
| X PUMP | ▭ CONVERSION PLANT |

TABLE 4.

ESTIMATED CAPITAL COST OF CONVERSION
PLANTS AT SALTON SEA STATE PARK

| <u>Item</u> | <u>Capital Cost</u> |
|--|---------------------|
| Saline water conversion plants, three 100,000-gallons per day capacity | \$ 625,000 |
| Pipelines | 10,000 |
| Three pumping plants, 100 gpm | 10,000 |
| Three tanks, 250,000 gallons each | 54,000 |
| | <hr/> |
| Subtotal: | \$ 699,000 |
| Administration and engineering, 10% | 70,000 |
| Contingencies, 25% | 175,000 |
| | <hr/> |
| | \$ 944,000 |

The process selected for the analysis was a multistage flash evaporator similar to the sea water demonstration plant which is now operating in San Diego, and has previously been described in this bulletin.

The Salton Sea area is one of relatively high-fuel cost. One of the most likely sources of fuel available for the operation of a distillation plant in that area is fuel oil delivered from the Los Angeles area. It is estimated that the cost of delivered fuel oil would be equivalent to 50-55 cents per million Btu. Because of this relatively high fuel cost, the performance ratio, i.e., the pounds of water produced per pound of steam condensed, should be made high in the design. In order to obtain a high performance ratio, a relatively large number of stages would be indicated. Actually, a range of 30-40 stages would probably be selected for a plant to operate at the Salton Sea. Since the plant at San Diego has 36 stages, the basic process is quite similar and the detailed description of the process will not be repeated in this section.

One important consideration is the prevention of scale in an evaporator. With sea water this can be accomplished by the addition of certain chemicals which either inhibit the scale or cause a decomposition of some of the scale-forming products. An examination of Table 3, which compares the composition of the water of the Salton Sea with Pacific Ocean water, shows that the calcium is about twice as concentrated and the sulfate is about

three times as concentrated in the Salton Sea as in the Pacific Ocean. Consequently, the scaling potential, especially of calcium sulfate, is much greater.

The control of calcium sulfate scale in operating plants is currently effected by keeping the concentration and temperature below values that cause saturation. For scale control of Salton Sea water it is necessary to remove one or the other of these ions in a pretreatment step. Because this water is a difficult water in terms of scaling potential, the cost estimate included an ion exchange bed to remove sufficient calcium to prevent scaling by calcium sulfate. In addition, acid would be required to decompose the carbonate to avoid scale by calcium carbonate and magnesium hydroxide. Such a procedure is normally called pH control of scale. With this rather elaborate method of scale control and by limiting the temperature to 195°, the scale could probably be prevented in the evaporators. However, because of the relatively low temperature of operation and the cost of scale prevention employed, the cost of the water was increased substantially over a similar operation on normal sea water. The operating cost of the three 100,000 gallons per day plants, when operated to produce an average of 160 acre-feet per annum, is approximately as follows:

| | |
|------------------------|---------------------|
| Fuel Oil | \$110 per acre-foot |
| Electrical energy | 11 |
| Chemicals | 32 |
| Materials and supplies | 10 |
| Maintenance | 25 |
| Operating labor | <u>62</u> |
| Total: | \$ <u>250</u> |

When the amortization costs are added, the equivalent annual cost is \$580 per acre-foot.

Economics of Conversion

The department is studying the application of saline water conversion practices to the development of waters otherwise unsuitable for their intended use. Such waters include sea water, brackish water, and treated waste water.

Because the economics of conversion is closely related to the techniques of conversion, a prime area of departmental interest is one of economics. In the past year, the department has surveyed many cost estimates and evaluated some of the more reliable estimates of saline water conversion which have been offered by designers, manufacturers, research institutions, engineering firms, and others. The preliminary results of this economic evaluation as it applies to conversion by electrodialysis, by distillation, and by the application of nuclear and solar energy, are discussed in this section of the bulletin. Some of these estimates are summarized in Table 5.

Electrodialysis - This is the most widely used process today for conversion of brackish waters. An example of a modern electrodialysis plant is the 650,000 gallons per day brackish water conversion plant recently completed by Ionics, Incorporated (6) for Buckeye, Arizona. At the actual load of slightly less than 50 percent of capacity, Ionics estimates the cost of

TABLE 5
CURRENT SEA AND BRACKISH WATER
CONVERSION COST ESTIMATES

| Source of Estimate | Date of Estimate | Status of Development | Size of Plant, g.p.d. | Type of Plant | Cost of Water \$/AF | Conditions |
|--|------------------|-----------------------|--------------------------|---|---------------------|--|
| Ionics | 1962 | In operation | 650,000 | Electrodialysis | 165 | Actual conditions with 48% load factor, 2,200 ppm feed reduced to 500 ppm. |
| Ionics | 1962 | In operation | 650,000 | Electrodialysis | 108 | Actual conditions with assumed 98% load factor, 2,200 ppm feed reduced to 500 ppm. |
| Ionics | 1961 | Current | 2,000,000 | Electrodialysis | 195 | 4,000 ppm feed reduced to 500 ppm. Today's technology. |
| Ionics | 1961 | Dev. required | 2,000,000 | Electrodialysis | 100 | Same as above, except for projected technological improvements within 5 years. |
| Ionics | 1961 | Current | 2,000,000 | Electrodialysis | 110 | 2,000 ppm feed reduced to 500 ppm. Today's technology. |
| Ionics | 1961 | Dev. required | 2,000,000 | Electrodialysis | 55 | Same as above, except for projected technological improvements within 5 years. |
| Westinghouse | 1962 | Current | 150 million | Multistage flash, with power generation 880 mwe | 130-135 | Private utility financing at 14% fixed charges. Fuel @ 40¢/million Btu, 200°F, brine temperature. |
| Westinghouse, with Financing modified by DWR | 1962 | Current | 150 million | Multistage flash, with power generation 880 mwe | 75-80 | Same plant but with State financing @ 4% interest rate. West Coast fuel @ 35¢/million Btu, 200°F, brine temperature. |
| Westinghouse, with financing modified by DWR | 1962 | Current | 150 million | Multistage flash, with power generation 880 mwe | below 75 | Same plant optimized for operations with 250°F, brine temperature. |
| Chicago Bridge & Iron | 1961 | Current | 10 million 20 million | Long-tube vertical distillation Long-tube vertical distillation | 195 130 | Based on design and operation of OSW demonstration plant at Freeport, Texas. OSW standard estimating procedure used. 250°F, brine temperature. |
| Fluor | 1959 | Current | 110 million | Multistage flash, with nuclear steam generator | 125 | Based on use of 957 mwt heavy-water-moderated nuclear reactor as steam source. |
| Fluor | 1959 | Dev. required | 130 million | Multistage flash, with nuclear steam generator | 102 | Conservative future technology with 957 mwt nuclear steam generator. 250°F, brine temperature. |
| Fluor | 1959 | Dev. required | 150 million | Multistage flash, with nuclear steam generator | 77 | Same as above except optimistic future technology and 275°F, brine temperature. |
| Fluor | 1959 | Current | 130 million | Multistage flash, with fossil-fueled steam generator and power plant. | 115 | Current technology. Net capacity of power plant 152 mw. |
| FMC Corporation | 1962 | Dev. required | 10 million | Direct contact distillation process | 160-195 | Brine temperature 280°F. Estimate based on OSW standardized procedure. |
| Marquardt Corp. | 1962 | Dev. required | 3 million | Multistage flash, combined with power generation | 143 | Gas-fires boiler. Diphenyl cycle. Net electrical power generation of 12,000 kw. |

TABLE 5 (Continued)

| Source of Estimate | Date of Estimate | Status of Development | Size of Plant, g.p.d. | Type of Plant | Cost of Water \$/AF | Conditions |
|----------------------|------------------|----------------------------------|-----------------------|--|---------------------|--|
| Marquardt Corp. | 1962 | Dev. required | 10 million | Multistage flash, combined with power generation | 114 | Gas-fired boiler. Diphenyl cycle. Net electrical power generation of 290 mw. Capacity of power plant with zero water production is 306 mw. Private financing of power plant and public financing of water plant assumed. |
| Marquardt Corp. | 1962 | Dev. required | 75 million | Multistage flash, combined with power generation | 75 | Same as above, except net electrical power generation of 205 mw. |
| Struthers Scientific | 1962 | Dev. required | 1 million | Freezing | 245 | Struthers-Umano direct contact process. |
| Struthers Scientific | 1962 | Dev. required | 10 million | Freezing | 147 | Struthers-Umano direct contact process. |
| Los Alamos (AEC) | 1962 | Extensive reactor dev. required. | 1 billion | Long-tube vertical distillation | 40 | Heat source is a nuclear reactor of fast breeder type. Reactor of this size cannot be built for number of years, though theory has been worked out. Experience with smaller sizes necessary first. |

water at the plant site of \$166 per acre-foot. On a full-load basis, the company estimates that the cost would be about \$100 per acre-foot. These estimates appear to be realistic costs for electrodialysis plants that can be built today.

For comparison, a recent estimate by the department of the canalside rates of water delivered through the authorized State Water Facilities to reservoirs in Southern California were estimated to average about \$65 per acre-foot.

The aqueduct water costs are not directly comparable with converted water costs. In the case of the brackish water conversion plant, local pumping and distribution costs would have to be added to obtain the cost to the consumer. In the case of reservoir storage water, costs of piping for gravity feed and local distribution costs would have to be added to obtain the cost to the consumer. To make a direct comparison, a specific case would have to be considered.

Distillation - Among sea water conversion processes, distillation is the only one that is used to any extent on a commercial scale. Actual costs of operating plants are very difficult to obtain, but it is probably safe to say that there are not many plants producing water for less than \$1.25/1,000 gallons. In contrast to the dearth of costs reflecting actual operating experience, there is no lack of estimates of proposed plants, many being based upon little more than laboratory testing. Others, however,

are the result of careful engineering studies and analysis by responsible companies and reliance may be placed upon them. Some of these are listed in Table 5.

One means of gaining economies in conversion by distillation is to combine power generation and conversion in the same plant. An interesting proposal was made by Westinghouse Electric Corporation (7) for such a plant. In this application low-pressure steam that has little value for power production would be used to heat saline water in a distillation process. The energy component of the water cost would be the value of the low-pressure steam to the power production unit. This value is considerably less than it would be if fuel were used directly to produce steam for the conversion plant.

Based on private utility financing and for large plants (up to 150,000,000 gpd), Westinghouse estimated the cost of converting sea water to be about \$135 per acre-foot.

The department has estimated that with municipal-type financing, the estimated cost of water would be reduced to about \$80 per acre-foot. Further reductions are in sight as a result of current technological improvements.

The advent of interconnected power systems within the State in a few years will make it possible to tie large-capacity base-loaded electric power stations to conversion plants. It is expected this will offer attractive conditions for combination plants in some parts of the State, especially in coastal areas.

Nuclear Energy - Since energy costs may range up to 50 percent of the total cost of converting sea water, such costs represent an attractive target for reduction. In fact, without effecting drastic reductions from present energy costs, there seems small hope that really impressive gains can be made in economics of conversion.

Hammond (8,9) has proposed that large fast-breeder thermal reactors be used to produce steam to distill saline water. Even though fast-breeder reactors have not been built on any scale so far, it is stated (8) that there appears to be no technical reasons why such reactors cannot be built. The attractiveness of these large capacity fast-breeder reactors is in the low cost of the energy produced. It has been estimated (8) that steam can be produced for about 12¢ per million Btu with a 1,700 mwt reactor, and 2.5¢ with a 25,000 mwt reactor. These reactors are capable of producing sufficient energy to supply saline water conversion plants with capacities of 100,000 and 1,000,000 acre-feet per year, respectively.

This proposed scheme was made formally (10) by the Atomic Energy Commission's Oak Ridge National Laboratory. It is now being evaluated by reactor development experts in the AEC.*

*A Task Group has been appointed with members of the AEC and the Department of the Interior to more completely evaluate the economics of large dual-purpose plants. It is expected a final report will be issued by the Task Group in 1963.

The original idea has been expanded (11) to include an evaluation of four reactor types, one close to existing technology and three more advanced concepts. The one closest to existing technology is a heavy-water-moderated, boiling light-water-cooled reactor.* The others include a fast-breeder and two thermal breeders. It is anticipated that the initial estimates will be firmed up by the additional evaluations planned for 1963.

While the fast-breeder reactor combined with a distillation process for conversion of saline water cannot be built today, the attractive economics are of considerable interest. The estimated cost (8) of converted water in plants with capacities of 100,000 and 1,000,000 acre-feet per year are about \$70 and \$35 per acre-foot, respectively. Hammond's estimate for a 15,000 acre-foot per year nuclear powered conversion plant of \$215 per acre-foot is not competitive with a conversion plant using fossil fuel at current prices in the State. This is because this reactor concept is not competitive with a conventional steam boiler in this size range of 150 mwt.

* Hammond has pointed out that a natural uranium heavy-water-moderated reactor burns a cheap fuel and produces enough plutonium credit at present prices to offset burnup and most other fueling costs when constructed in large size. Because such a reactor could be built today, it may be a strong contender for sea water conversion in the near future.

Solar Energy - The department had previously had an evaluation (12) made of the possibility of using solar energy to heat large amounts of saline water in ponds covered with layers of plastic glazing. The heated water was to be evaporated in a multistage flash evaporator to conserve energy. A paper was prepared by the department based on this more extensive report for presentation at a symposium (13) of the American Chemical Society on saline water conversion. A summary of the report is given in Appendix B.

The main conclusion reached was that, at the present time, in most of the State the price of alternative sources of energy is less than the cost of capturing solar heat; hence, other energy sources would normally be selected. However, the cost is such that in some of the isolated desert areas of the State there may be an application in the future, provided a demand develops for additional water.

Survey of Brackish Water Areas

A reconnaissance study of selected communities in Southern California where saline water conversion might be employed in the future, revealed twelve potential sites. The means of determining the sites was fairly selective as can be seen from the following criteria:

1. Alternative fresh water supplies would either be nonexistent or very expensive.

2. A supply of saline water would be readily available.
3. A present or future demand for fresh water existed.
4. Survey excluded areas within general service area of the California Aqueduct, with the exception of some "fringe areas."
5. Areas were already presently developed or partially developed and converted water would only augment the present supply.
6. Survey generally included only those areas in which the total dissolved solids of the available water averaged more than 1,500 ppm.

The twelve localities, together with the information presently available, are tabulated in Table 6. Data on which to base accurate predictions are in many cases not available. Consequently, much of the information presented in Table 6 can only be used as a guide or an indication of a trend. A survey of local conditions, in order to obtain more accurate information, would probably be warranted for areas in which a trend toward poorer quality is indicated as the water use or reuse is intensified.

The New and Alamo Rivers area represent a yield of 350,000 acre-feet per annum which is available for exchange. San Diego, for example, might be able to increase its supply from the Colorado River by converting the saline water from the New and Alamo Rivers for use by consumers in the vicinity of the two rivers.

TABLE 6
BASIC DATA ON AREAS IN SOUTHERN CALIFORNIA
FOR POSSIBLE SITES FOR SALINE WATER CONVERSION PLANTS

| Location | Estimated Demand ^a | | Present Water Supply | | Saline Water | | Estimated minimum cost of alternative supply to meet estimated future demand, \$/acre-ft. c | Source of Alternative Supply |
|---|-------------------------------|------------------------|--------------------------|-------------------------------|--------------------------------------|-------------------------------|---|--------------------------------------|
| | Present | Future | Quality TDS in ppm | Amount acre-feet/yr | Source | TDS Range ^b in ppm | | |
| Amboy | Less than 100 | less than 1000 | 305 300 | 500-700 200-300 | Bristol Valley ground water | 1,500-330,000 | 180 ^d | Twentynine Palms |
| Baker | Less than 60 | between 1000 and 5000 | 1000 1500 | unknown " | Soda Lake Valley ground water | 1,500 - 8,300 | 100 ^d | Mojave River Basin and Afton Canyon. |
| Interior Death Valley | Less than 100 | less than 1000 | 600 1400 | 4400 | Death Valley ground water | 1,500 - 12,500 | 380 ^d | Indian Wells Valley |
| New and Alamo Rivers | - | approx. 350,000 yields | - | - | New and Alamo Rivers surface waters. | 1,500 - 5,000 | - | - |
| NE side of Salton Sea | Less than 100 | less than 5000 | 1000 2000 | unknown | Salton Sea East ground water | 1,500 - 24,000 | 35 ^f | Coachella Valley |
| Randsburg - Red Mountain | Less than 100 | less than 1000 | 400 | unknown | Fremont Valley ground water | 1,500 - 56,500 | 120 ^d | Indian Wells Valley |
| Randsburg - Red Mountain | Less than 100 | less than 1000 | - | - | Cuddeback Valley ground water | 1,500 - 5,600 | 120 ^d | Indian Wells Valley |
| Ridgecrest - Inyokern - China Lake ^g | Less than 4000 | less than 8000 | 360-4200 260- 450 | 4000-7000 1000-3000 | Indian Wells Valley ground water | 1,500-231,000 | 75 ^d | Fremont Valley |
| Trona | Approx. 1000 | less than 2000 | 340 290- 406 | 100- 300 1000 ^h | Searles Valley ground water | 2,100-370,000 | - | - |
| Avalon | Less than 300 | less than 2000 | 596-1106 (up to 1500) | - | Pacific Ocean | 33,600 | - | - |
| Cuyama | Less than 300 | between 1000 and 5000 | 1,750 | 1000+ | Cuyama Valley ground water | 1,500- 4,000 | 145 ^f | Santa Maria |
| Lompoc | Less than 3000 | less than 5000 | 1,350 | 2300+ | Lompoc Subarea ground water | 1,500- 3,800 | 55 ^f | Santa Maria |
| Santa Maria | Less than 4000 | less than 8000 | 600 - 700 | unknown | Santa Maria Valley ground water | 1,000- 1,800 | 45 ^f | Lompoc |

Footnotes:

- Present and future estimated water demand. Present demand was based upon estimated per capita use and 1960 census figures, or upon data available in departmental reports. Both present and future use must be considered very conjectural.
- These data were determined from recent water quality data.
- Costs of alternative supply which were based upon preliminary cost analyses of supplying potable water from the closest source available. It must be noted that these sources are usually from basins of limited recharge capability, such as the desert areas, where water is already being essentially mined; or they are from areas where present development leaves little surplus water for export and where future development might very well cause basin depletion. It must also be noted that these costs were computed for maximum estimated future demands; costs would increase if lesser quantities were delivered.
- Alternative source from basin of limited recharge ability.
- Available for exchange -- this is not an estimate of local demand.
- Alternative source from basin where present development leaves little surplus water for export.
- Not a source of domestic supply.
- Supplied from wells in Indian Wells Valley and fixed by contract.

San Diego could then in turn take in exchange water from the Colorado River through the Metropolitan Water District aqueduct to augment its supply in an amount equal to the amount of saline river water converted.

The alternative sources listed in the tabulation are in all cases limited either by recharge ability or for exportation. In the case of the three cities of Cuyama, Lompoc, and Santa Maria, relatively near the coast, the alternative sources are Lompoc for Santa Maria and Santa Maria for Lompoc or Cuyama, which leaves little assurance that water would be available for export.

Representatives of both Santa Barbara and San Luis Obispo Counties feel confident that local water supplies will permit economic progress to continue normally for about twenty years without need of imported water. These counties have a contract with the department which commits them to purchase water, but allows a delay of up to twenty years before the aqueduct is built. In the interim some areas in these counties may very well make use of supplemental water by saline water conversion. Having a readily available alternative source of water also allows plans to be made on a shorter term basis, which normally means more accurate predictions can be made.

Use of water for lawns and similar purposes in the Trona area has been discouraged not only by a limited supply, but also because of the rate structure which increases with increased use. This and other water conservation practices can stretch a given

supply. Because of the imponderables involved, accurate predictions of future demands in the areas cited in the table are difficult if not impossible to make.

The summary was limited to areas in which salinity averaged more than 1,500 ppm. If the survey had included the 1,000-1,500 ppm range, at least 1,000 areas, mostly small, would have been included. Much of Ventura County, including Filmore and Oxnard, would be included.

By excluding areas within the general service area of the California Aqueduct, coastal areas in San Diego and Orange Counties were excluded. There may well be, however, local conditions in these counties and other areas that have small but mineralized ground water basins that will dictate the use of brackish water conversion, possibly to meet future standards for domestic water supply.

Public health aspects of the use of water with relatively high total dissolved solids remain to be resolved by the Department of Public Health. The issuance of temporary permits for use of water greater than 1,000 ppm total dissolved solids is a complex subject. The Department of Public Health has planned a program which, when completed, should serve as a guide in establishing limits of dissolved solids for domestic water supply. The program has not yet been initiated.

Temporary permits are currently issued for use of water with up to 1,500 ppm of total dissolved solids. The temporary

permit will be in effect in most cases until Department of Public Health standards are established, or until the problem is resolved by the development of a water supply of better quality. A special hearing is required before the State Board of Public Health will permit the use of domestic water containing more than 1,500 ppm of total dissolved solids.

Once limits of dissolved solids have been firmly established, temporary permits to use water containing a greater amount of dissolved solids would have a definite time limit. After limits of dissolved solids have been established by the Board, the estimation of the application of converted brackish water can be made with more accuracy. As growth occurs in these and others of the numerous communities dependent upon water supplies of relatively high salinity, new sources of supply are likely to be of lower quality. It is anticipated that conversion will become increasingly important as a means of extending a water supply or of making available new sources, otherwise unusable.

Currently, the State Department of Public Health lists nine areas (14) of the state which do not presently have public water supplies meeting the "full" permit requirements of that department because of excess salinity. The following is a list of the areas:

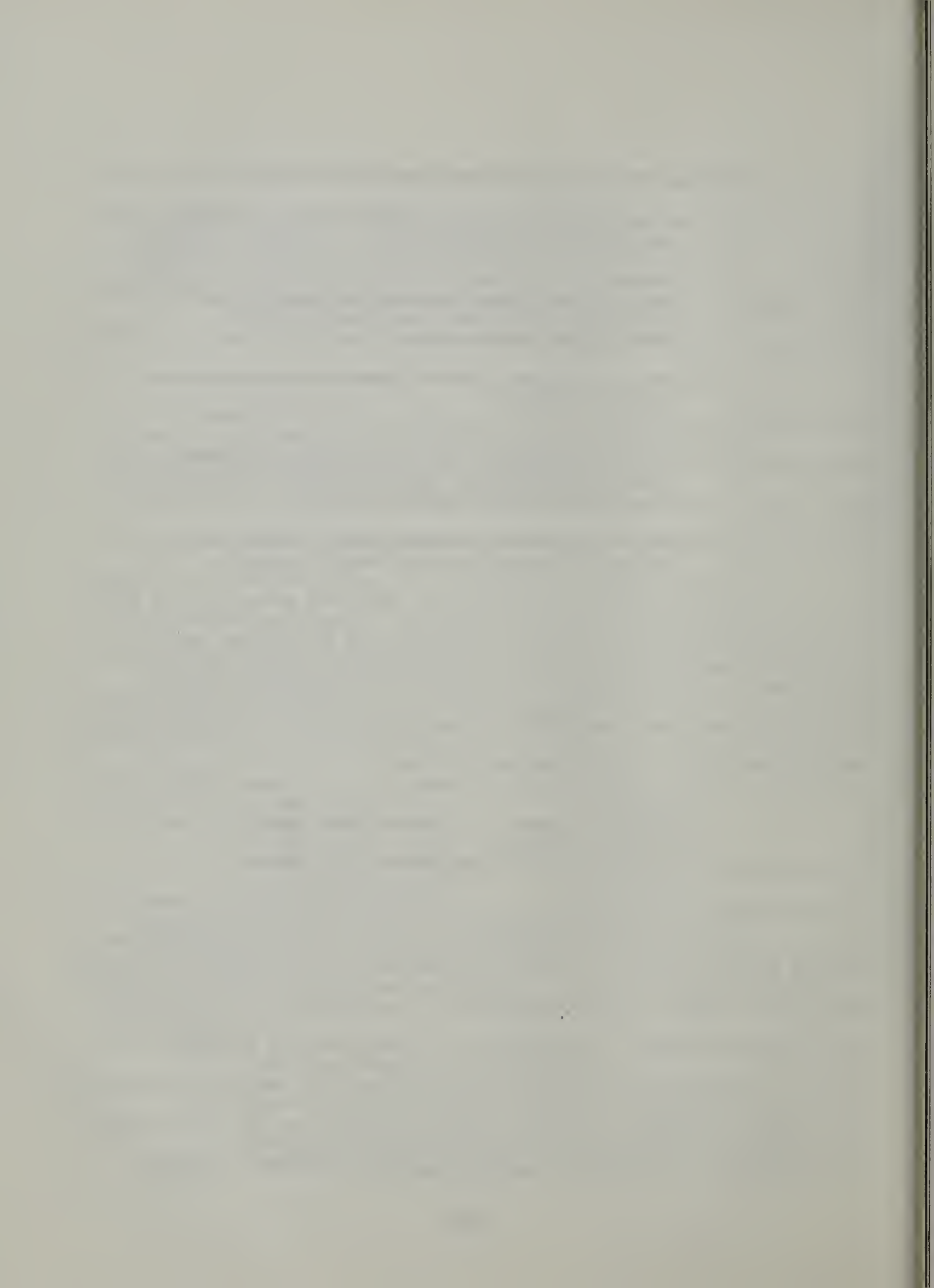
1. San Diego County coastal basins.
2. The San Juan Capistrano area of Orange County.
3. The Salton Sea-Coachella Valley area of Imperial and Riverside Counties.

4. The Chino area of San Bernardino County.
5. The upper Mojave Desert Basin lying in parts of Los Angeles, San Bernardino and Kern Counties.
6. A number of the Ventura County basins including Simi Valley, the vicinity of Oxnard, the vicinity of Ventura, and parts of the Santa Clara River Basin.
7. Parts of coastal ground water basins in Santa Barbara County.
8. Santa Barbara, Lompoc, and Santa Maria and portions of Santa Barbara, San Luis Obispo and Kern Counties extending from Maricopa, Cuyama, into the Cholame and Parkfield areas.
9. Some of the inland ground water basins of Monterey County and San Benito County.

In order to more completely evaluate areas in the State in which brackish water occur, an inventory of saline water is being made. A preliminary inventory for Northern and Central California has been completed. Areas of different total dissolved solids have been categorized as follows:

| | |
|-------------------|------------------|
| Nonsaline | 0- 1,500 ppm |
| Slightly saline | 1,500- 3,000 ppm |
| Moderately saline | 3,000- 5,000 ppm |
| Saline | 5,000-10,000 ppm |
| Very saline | over 10,000 ppm |

It is anticipated that in some of the areas having saline ground waters, future requirements of water quality improvement will result in an application of conversion for the removal of dissolved solids. In addition, information on brackish water areas is expected to be used in the planning of water requirements and project staging as these studies progress to the point where the conversion processes can be integrated into the program.



PART II. OTHER CONVERSION ACTIVITIES
WITHIN CALIFORNIA

A. UNIVERSITY OF CALIFORNIA

INTRODUCTION

Saline water conversion research began at the university during the fiscal year 1951-52. The objective of the university in conducting research work in saline water conversion is to perfect or develop means of obtaining potable water from saline sources at costs competitive with alternative sources of supply. Because removal of dissolved solids from brackish water and waste water is expected to be less costly than removal of solids from more saline sources or sea water, increasing attention is being given to research methods appropriate to these less saline sources.

The research activity has been sustained at nearly the same level for several years. During the current fiscal year the State Legislature appropriated \$334,900 for conversion research (15). Some additional funds are also made available by the Water Resources Center of the university. The total of the current budget is \$432,957.

The university conducts the research and development at its Berkeley campus, Richmond Field Station, Los Angeles campus, and the San Diego campus. The facility at the San Diego campus was completed last year. It is a building located adjacent to the inshore end of the pier used by the Scripps Institution of Oceanography. The primary purpose of this facility is to test processes that have reached the pilot plant stage and for which a supply of

clean, full-strength sea water is desired. The rotating still described in the section of current projects has been installed and initial tests are now under way. Testing of a membrane suitable for a reverse osmosis application was initiated later in the year.

REPORTS

The university issues annual progress reports (16,17) in which the work in progress is described. In addition, several detailed reports on specific projects were issued during 1962. A list of these reports is given in Table 7. Copies of these reports may be obtained from the university.*

*From Sea Water Conversion Laboratory, University of California, 1301 South 46th Street, Richmond, California.

TABLE 7
REPORTS ISSUED DURING 1962 BY UNIVERSITY OF CALIFORNIA
WATER RESOURCES CENTER, SEA WATER CONVERSION PROGRAM

| TITLE | WATER RESOURCES CENTER No. | UNIV. REPT. No. | DATE | AUTHOR |
|--|----------------------------------|-----------------------|-----------|--|
| "DETERMINATION OF COEFFICIENTS FOR THERMODYNAMIC EQUATIONS FOR DETERMINING THE PROPERTIES OF SEA WATER, PARTICULARLY VAPOR PRESSURE" | 44 | 61-80 | FEB. 1962 | CHARLES GASTALOO |
| "EFFECT OF STRESS ON THE ELECTRODE POTENTIAL OF SILVER, STEEL AND BRASS IN AQUEOUS SOLUTIONS." | 49 | 62-12 | MAR. 1962 | KEN NOBE SWIE-IN TAN |
| "SALT WATER DEMINERALIZATION WITH A MODIFIED AQUAFRESH ELECTRODIALYTIC STACK." | 51 | 75-28 | MAY 1962 | PASCAL M. RAPIER SUSAN WEINER WALTER K. BAKER |
| "SEA WATER DEMINERALIZATION BY MEANS OF A SEMIPERMEABLE MEMBRANE." | 52 | 62-26 | JUNE 1962 | S. LOEB |
| "SALINE WATER RESEARCH - PROGRESS SUMMARY, JUNE 1962" | 54 | 62-33 | JULY 1962 | --- |
| "EFFECT OF ILLUMINATION ON THE ELECTRODE POTENTIAL OF COPPER AND SILVER SINGLE CRYSTALS IN AQUEOUS SOLUTIONS." | 55 | 62-35 | AUG. 1962 | KEN NOBE D. A. CHANCE |
| EFFECT OF MONOCHROMATIC ILLUMINATION ON THE ELECTRODE POTENTIAL OF COPPER AND TIN IN AQUEOUS SOLUTIONS." | 57 | 62-40 | AUG. 1962 | H. A. ARBIT K. NOBE |
| "SEA WATER DEMINERALIZATION BY MEANS OF A SEMIPERMEABLE MEMBRANE," - PROGRESS REPORT JULY 1, 1961 - DECEMBER 31, 1961. | 58 | 62-41 | AUG. 1962 | S. LOEB |
| "SALINE WATER DEMINERALIZATION BY ELECTRODIALYSIS WITH COMPONENTS MANUFACTURED BY IONICS, INC." | 59 | 75-29 | AUG. 1962 | PASCAL M. RAPIER WALTER K. BAKER SUSAN A. WEINER |
| "BERKELEY PROGRESS REPORT FOR THE YEAR ENDING JUNE 30, 1962." | 60 | 75-30 | AUG. 1962 | --- |
| "CONDENSATION COEFFICIENT OF WATER" | 62 | --- | OCT. 1962 | KHOSROW NABAVIAN LEROY A. BROMLEY |
| "DESIGN, DEVELOPMENT & TESTING OF A 600-GAL. PER DAY OSMOTIC SEA WATER DESALINIZATION CELL." | 63 | 62-53 | NOV. 1962 | S. LOEB F. MILSTEIN |
| "SEA WATER DEMIN. BY MEANS OF A SEMI-PERMEABLE MEMBRANE" (PROGRESS REPT. JAN. 1 TO 6/30/62) | 66 | 62-61 | DEC. 1962 | S. LOEB |

PROJECTS

A brief description of the research and development projects in progress during 1962 at the several campuses of the university, are contained in this section. For detailed information, the reader is referred to the university's annual reports (16,17) and special reports of the Sea Water Conversion Program as listed in Table 7.

1. Electrodialysis. In this project the objectives are to determine the optimum conditions under which to operate electrodialysis apparatus considering the effects of polarization and scaling on current density. Attention is also being directed to the design of electrodialysis stacks in which the energy demand is minimized when operated with waters of high salinity.
2. Carryover Studies. In this project the objectives are to measure the fog carried over into the condenser by the steam formed during the flash evaporation of warm water and to develop a device for minimizing the amount of such carryover.
3. Scale Studies. In this project the objectives are to determine the equilibrium scaling tendencies in saline water concentrates at temperature above the normal boiling point and to formulate equations or charts to represent the data obtained.

4. Ion Exchange. In this project the objectives are to study the use of exchange materials for the softening of sea water with regeneration by the concentrated brine and to investigate the energy requirements of selected exchange materials.
5. Direct Contact Heat Transfer. In this project the objectives are to develop devices for the exchange of heat between saline water and a liquid which is immiscible with water and to incorporate the devices into a pilot plant.
6. Freeze-Separation. In this project the objectives are to obtain fundamental data on the solubility of carbon dioxide in saline solutions and to make a design study of a system for conversion using carbon dioxide hydrate.
7. Thermodynamic Studies. In this project the objectives are to evaluate the implications of thermodynamics on several methods of conversion and to evaluate the theoretical gains to be made by increasing the brine temperature in distillation processes.
8. Solar Distillation Studies. In this project the objectives are to test the latest designs of solar stills evolved by the project and to evaluate solar energy collectors without the use of a glass cover.
9. Multiple Effect Rotating Still. In this project the objectives are to test a previously developed pilot plant on sea water and to evaluate the results of the operation.

10. Capillary Control of Vapor Transfer Gap. In this project the primary objectives are to demonstrate that thin films of vaporizing solutions can be held at very close and uniform distance (0.010") from each other and to develop and construct experimental sheets that can be used in the tests. Pertinent data are also being measured.
11. Pilot Plant Development. The current objective in this project is to investigate methods of scale control in distillation plants through in situ seeding techniques at elevated temperature.
12. Demineralization by Means of a Semipermeable Membrane. In this project the objectives are to develop membranes suitable for the reverse osmosis process and to investigate the nature of the associated apparatus required for the separation. In addition, pilot plant equipment is being tested on saline water.
13. Techniques of Optimization. This is a project in which the objectives are to study the theoretical relationships of thermodynamics and economics on saline water conversion. The theoretical calculations are applied to the optimization of the operation of conversion processes.

14. Transport Phenomena Near a Liquid-Vapor Interface.

In this project the objectives are to obtain basic information on mass and heat fluxes near a liquid-vapor interface and to study the kinetics of steady and non-steady state evaporation.

15. Experimental Heat Transfer Studies. In this project the objectives are to investigate the physical factors influencing the evaporation of saline water from wiped and falling films. The effect of flow rate, temperature and temperature difference, pressure, salinity and feed distribution on evaporator performance, geometry and environment are being investigated.

16. Waste Water Reclamation Biological Systems. In this project the objectives are to study the removal of dissolved materials, including viruses and detergents, by prolific algae growth. These studies are conducted with both bench scale and pilot plant equipment utilizing both raw and treated waste water. Feasibility of practical application of activated-sludge-algae-pond processed water to actual sites will be investigated.

17. Corrosion Studies. In this project the objectives are to obtain fundamental knowledge of metal behavior in aqueous solution under various conditions.

B. OTHER AGENCIES

In addition to state agencies, other public agencies and private companies are involved in saline water conversion within California. These activities are described in this section.

COALINGA

The electrodialysis conversion plant at Coalinga was the first in the United States to use converted water for a municipal supply. The plant which has been in operation since 1959 has completed another successful year during 1962. The final payment for the plant was made out of water revenues in September 1962.

Details of the plant and equipment have been previously described (1,18,19,20,21). The feed to the electrodialysis unit is from local wells. The salt concentration varies somewhat. The range of total dissolved solids is usually from 2,100 to 2,400 ppm. The product is normally below 500 ppm. Typical analyses of raw well water and demineralized product water distributed in Coalinga in March and August 1962 are given in Table 8.

TABLE 8
REPORT OF CHEMICAL ANALYSIS OF COALINGA WATER¹

| DESCRIPTION | MARCH 1962 | | AUGUST 1962 | |
|-----------------------------|-----------------------------|---------------------------------------|-----------------------------|---------------------------------------|
| | RAW WELL WATER COMPOSITE | DEMINERALIZED PRODUCT COMPOSITE | RAW WELL WATER COMPOSITE | DEMINERALIZED PRODUCT COMPOSITE |
| TOTAL SOLIDS PPM | 2180 | 388 | 2700 | 568 |
| HARDNESS PPM | 584 | 37.5 | 801 | 86 |
| ALKALINITY PPM | 130 | 14.0 | 121 | 29 |
| CALCIUM PPM | 132 | 8.0 | 169 | 15.6 |
| MAGNESIUM PPM | 57.1 | 4.3 | 92.4 | 11.5 |
| IRON (TOTAL) PPM | < 0.1 | < 0.1 | 0.04 | 0.03 |
| MANGANESE PPM | 0.21 | < 0.05 | 0.05 | < 0.05 |
| SODIUM PPM | 423 | 80 | 512 | 126 |
| POTASSIUM PPM | 14.4 | 1.1 | 11 | 1.7 |
| BORON PPM | 2.8 | 2.8 | 2.1 | 2.3 |
| CHLORIDES PPM | 209 | 7.5 | 340 | 29.2 |
| SULFATES PPM | 1060 | 189 | 1250 | 287 |
| FLUORIDES PPM | 0.2 | 0.1 | 0.15 | 0.15 |
| NITRATES AS NITROGEN PPM | 0.75 | < 0.1 | 0.75 | 0.2 |
| PH | 8.2 | 7.2 | 8.2 | 7.8 |

(1) - REPORTED BY STATE DEPARTMENT OF PUBLIC HEALTH

OFFICE OF SALINE WATER

In the federal government, the Office of Saline Water (OSW), is assigned primary responsibility for the research and development on saline water conversion. The OSW contracts all of the work to other government agencies, universities, and to private companies throughout the United States and this year it entered into a contract with a company located in England (22). The activities of the OSW are adequately described in its annual reports.* For additional information about the OSW, the reader is referred to those reports.

During the year the OSW announced the availability of nine research and development progress reports. A list of these reports is tabulated in Table 9. Each progress report covers in detail the work done by a particular contractor on a specific process or conversion technique. In addition, the proceedings of a saline water conversion conference were published (23).

Several of the contracts entered into during 1962 by OSW have been with agencies and companies in California. The scope of the work under OSW contract within the State is briefly described in this section of the bulletin.

Demonstration Plant

The operation and design of the multistage flash evaporator demonstration plant at San Diego has been previously described (1,2,3,4). A brief process description is included in Part I of the bulletin.

*OSW Annual Reports 1954-1961.

TABLE 9
OFFICE OF SALINE WATER
RESEARCH AND DEVELOPMENT PROGRESS REPORTS
(AVAILABLE IN 1962)

| <u>No.</u> | <u>TITLE</u> | <u>PB ORDER No.*</u> |
|------------|--|----------------------|
| 50. | "STUDY AND EVALUATION OF SOLAR SEA WATER STILL (SEPT. '61) | 171934 |
| 51. | "INVESTIGATION AND DEVELOPMENT OF AN ELECTROLYTIC SYSTEM FOR THE CONVERSION OF SALINE AND BRACKISH WATER" (AUG. 1961) | 171929 |
| 52. | "SURVEY OF PHYSIOLOGICAL MECHANISMS OF SODIUM AND CHLORIDE ION TRANSPORT AND DESIGN OF EXPERIMENT FOR APPLICATION TO DEMINERALIZING SALINE WATERS," PART. 1 "LABORATORY EVALUATION OF USE OF ALGAE IN SALINE WATER CONVERSION. PHASE 1 FINAL REPORT," PART. 2. (SEPT. 1961) | 171930 |
| 54. | "EVALUATION OF A THIN-FILM SEA WATER DISTILLATION UNIT FOR MARINE AND SHORE BASE APPLICATIONS." | 181041 |
| 55. | "DEVELOPMENT OF THE SOLVENT DEMINERALIZATION OF SALINE WATER. " (SEPT. 1961) | 181036 |
| 56. | "VAPOR COMPRESSION WITH SECONDARY HEAT-TRANSFER MEDIA." (DEC. 1961) | 181090 |
| 57. | "REMOVAL OF SCALE-FORMING COMPOUNDS FROM SEA WATER." | 181118 |
| 58. | "DEMINERALIZATION OF SALINE WATER BY ELECTRICALLY--INDUCED ADSORPTION ON POROUS CARBON ELECTRODES." (MARCH 1962) | 181142 |
| 60. | "DEVELOPMENT OF AN IMPROVED SOLAR STILL." (MARCH 1962) | 181144 |

*AVAILABLE FROM OFFICE OF TECHNICAL SERVICES,
U.S. DEPARTMENT OF COMMERCE, WASHINGTON 25, D. C.

During the early part of the year, Westinghouse Electric Corporation, the construction contractor, completed the plant startup phase and turned the plant over to the OSW on March 5, 1962.

In January 1962, the OSW announced (24) the selection of Burns and Roe, Incorporated, to manage and operate the plant under a cost-reimbursable-plus-fixed-fee contract. The estimated cost (25) to the government under this contract for fiscal year 1962 (December 20, 1961-June 30, 1962) is \$106,786. This is exclusive of the cost of fuel and electric power which was estimated to amount to about \$125,000 per year. The Burns and Roe contract was renewed (26) for fiscal year 1963 for \$200,732.

The plant was dedicated March 10, 1962, by Secretary of the Interior Stewart L. Udall, Governor Edmund G. Brown, and other national and local civic leaders. It was estimated that about 2,500 people attended the dedication. A majority of the people toured the facility and tasted the product water.

The cost of the construction and initial startup of the plant was \$1,663,246. The State contributed one-half of the cost of construction.

The plant has not been in operation a sufficient length of time for any formal reports to have been prepared. The Office of Saline Water plans to issue reports at appropriate intervals. The first report is planned for the period March 1962-June 1963. In general, the multistage flash process has performed according

to expectation. The operation of the plant has been gradually improved as more has been learned about the process.

Intimately related to the overall operation, but not the process per se, is the sea water feed to the plant. Considerable amounts of sea grass and kelp are drawn through the intake line into the intake pit. This material has caused considerable difficulty in various parts of the plant. The downtime required to clean such material out of the equipment has resulted in a reduced output.

Modifications made to the intake facility have reduced the amount of marine growth getting into the plant. However, these have not been completely effective and the OSW is now considering major revisions of the intake facility, which should greatly reduce the amount of marine growth that gets into the plant. It is encouraging that none of the major intake facilities operated by the power companies along the coast of California experience this type of marine growth in the intake facilities, indicating marine growth is more of an isolated problem, rather than extending along most of the coast.

Research and Development.

The Office of Saline Water had ten organizations within the State under contract during 1962, to perform research and development work in saline water conversion. The scope of the work of each contractor is described in this section.

Aerojet-General Corporation was awarded three contracts (26,27) totaling \$293,400 by the Office of Saline Water to conduct basic research and development work in the reverse osmosis process. This process was pioneered by the University of California (28,29).

The work under the contracts was started during the last half of 1962. The basic research program is aimed at developing membranes suitable for the reverse osmosis process. It will include a fundamental study of the mechanism of water transport and ion migration through membranes.

In the development contract the company is testing and evaluating membranes in a 1,000 gallons per day pilot plant. The design and testing of concepts for process equipment is also a part of the program.

Bechtel Corporation was awarded a contract for \$49,210 to determine the optimum size of saline water conversion plants (30). The study included an analysis of the effect of plant size on the cost of fresh water obtained from saline water. The processes evaluated are the three now in actual operation as part of the OSW demonstration plant program. The processes are long-tube vertical multiple effect evaporation, multistage evaporation, and electrodialysis. Details of the analysis are expected to be available in 1963.

The basis of the analysis was the demonstration plants for which some actual cost and operating data are available. Bechtel separated the cost of the experimental features to arrive at a cost representative of an actual production plant of the

same size as the corresponding demonstration plant. The equipment and cost estimates were then scaled to large capacity plants. Curves were prepared showing the effect of plant capacity on the cost of water.

More recently (27) the company was awarded a contract for \$85,200 to conduct cost studies pertaining to various sizes of large-scale saline water conversion plants. The work was begun near the end of the year.

FMC Corporation constructed a 4,600 gallon per day vapor reheat distillation process pilot plant utilizing liquid-liquid heat exchangers under a \$139,750 contract. The contract was awarded late in 1961 by the Office of Saline Water (31).

In the system under development, twin columns of oil are used as the heat exchanger. Fresh water is cooled in one column and sea water is heated in the other column, while the oil flows through both columns in a closed loop. In the vapor reheat process, the metallic heat exchange surface used in conventional distillation processes is eliminated.

Under the contract, FMC built and tested equipment to evaluate two oil liquid-liquid heat exchangers and a vapor reheat column. These two components were then tested as an integrated pilot plant utilizing a 5-stage column. This concept has been under development for several years. The prior work has been reported (32).

During the year the Office of Saline Water made two extensions to the contract (26,30) for \$80,000 and \$30,000, respectively, for the company to continue the investigation and analysis of heat-exchange without metallic heat-exchange surfaces for use with its vapor reheat process.

The economics of a large capacity conversion plant (10 million gpd) utilizing this process have been evaluated by the FMC Corporation. In a full-scale plant, the outer shell may be as much as 50 feet in diameter and probably be constructed of prestressed concrete. The estimated cost of water from such a plant is in the range of 50 to 60 cents per 1,000 gallons (23) when based on OSW standardized cost procedures (33).

Ford Motor Company, Aeronutronic Division, was awarded a contract (34) by OSW for \$69,872 late in 1962. The majority of the work will be performed in 1963. The contract is for basic research in the field of thermal diffusion (35). The principle involved is based on the separation obtained in a multicomponent system as a result of a concentration gradient that can be induced by a thermal gradient. Substantial concentration gradients have been observed in the steady state.

The work will be basic research conducted in the laboratory. Once the parameters have been established, the laboratory work will consist of making measurements on appropriately chosen variables.

It is not expected that thermal diffusion will necessarily become a commercial conversion process. However, basic research of this type on thermal diffusion and mass diffusion should give answers which may improve current saline water conversion processes.

General Dynamics Corporation, General Atomic Division, was awarded a \$150,000 contract by OSW in May 1962 to study a process utilizing a combination of membranes and pressure, which is known as reverse osmosis. Much of the prior fundamental work on this process was done by the University of California (28,29, 36,37). This process has the potential advantage of requiring less energy than other conversion processes. It may also find application in waste water reclamation.

In this process the usual osmotic process of spontaneous selective flow of a less concentrated liquid solution to a more concentrated solution through a semipermeable membrane is reversed by applying high pressure on the more concentrated solution. When this technique is applied to saline water, salt is held up by the semipermeable membrane and water containing much less salt collects on the other side.

General Atomic is conducting preliminary work and evaluating the physical and chemical characteristics of selected membrane materials to find a material that will permit a high reverse flow rate and not deteriorate in salt water.

Leslie Salt Company was awarded a contract (26) for \$15,000 by the Office of Saline Water to study the technical and economic feasibility of recovering fresh water from sea water in conjunction with solar salt-producing operations. The work done during 1962 consisted of a literature survey and an evaluation of the combination.

The company has concluded that a floating plastic condenser appears to offer an attractive means of water and salt production in many areas of the world. An additional advantage of the floating condenser, especially in areas where rainfall is significant, is that it prevents dilution of the brine by rain. This has the effect of increasing the net annual evaporation rate.

There is very little information available on the application of solar collectors to large ponds as found in the salt industry. Experimental work is indicated in order to evaluate the economic feasibility of this combination of water and salt production.

Narmco Research & Development was awarded a contract by the Office of Saline Water for \$35,730 to predict the influence of materials and operational variables on the effectiveness and performance of the vapor gap osmotic distillation process. The State of California, Department of Water Resources is contributing 50 percent of the cost of the contract.

This concept was developed by the University of California (38,39,40,41). A description of the process is contained in the section of the bulletin devoted to the activities at the university.

Narmco is analyzing the effects of temperature, pressure, geometry, and other variables on the efficiency of the process. It is determining qualitatively the effects of fluid-flow through porous media and membranes, water vapor diffusion through gas-filled gaps and backward diffusion of dissolved molecules in fluid through osmotic membranes. The company also plans to perform laboratory tests determined to be necessary to verify theoretical analysis.

A survey is also being made of the properties of existing materials to determine applicability of these materials for direct incorporation into test module designs.

Stanford Research Institute was awarded a \$31,200 contract by the Office of Saline Water (30) to conduct research on crystalline monomolecular membranes of controllable permeability. The work is primarily concerned with the synthesis of two dimensional crystals in which holes exist to allow passage of ions and molecules below a specific size.

During 1962 crystalline sheet polymers were prepared that may be useful in ultrafiltration. The specific application is in the removal of dissolved ions from saline solutions.

A membrane that contains pores or interstices of molecular dimensions is desired. Such a membrane would permit the passage of the small water molecules, but not the larger hydrated ions of sodium, chloride, and other ionized salts.

There are two parts to the program (42). One part is concerned with the synthesis of the necessary low molecular weight reactants and the other with the interaction of these reactants in dilute solutions. The interaction takes place either at a liquid surface or at the interface between two liquids.

Another contract (27) was awarded late in 1962 for \$35,000 to study the methodology for comparative engineering analysis of alternative processes for saline water conversion.

The University of California was awarded a contract (30) for \$39,010 to conduct research in salt transport mechanics and salt tolerance of plants. The research is being conducted by Dr. Emanuel Epstein at the Davis campus.

One part of the experimental study is concerned with studying living cells especially the physiological and biochemical processes of plants. Since plants are most effective in salt removal and selectivity, more knowledge is needed on the mechanism. As more information is developed, it may be possible to obtain membranes from plants suitable for use in dialysis processes. Another possibility is that the knowledge can be applied to the manufacture of more effective synthetic membranes.

The other part of the contract involves the development or creation of useful plants that can stand a higher level of salinity than existing useful plants. In irrigation, agriculture salt relations of plants are extremely important. Even a small

increase of salt tolerance of existing crop species would extend the usefulness of present or potential supplies of water which may be too saline for the plants at present.

Western Independent Research Laboratories was awarded a one-year contract (30) by the Office of Saline Water for \$54,007 to perform exploratory studies on demineralization of water through pressurization cycles on ion exchange materials. The work under this contract has included both a technical dissertation on theory and basic laboratory investigations with saline solutions.

The theoretical energy of separation is very low, hence the process is potentially attractive. The concept is based on the Donnan membrane equilibrium theory of electrolytes. In the particular application conventional ion exchange particles are used. Very high internal pressures build up during the separation of electrolyte from water. The purified water can be removed from the exchange material by pressure.

UNITED STATES NAVY

The U. S. Navy, at its Civil Engineering Laboratory (NCEL) at Port Hueneme, operates a marine testing facility for saline water conversion equipment which is of interest in its operations.

The Navy is interested in portable land-based or ship-board equipment. It evaluates the operating characteristics of the equipment and runs independent tests.

During the year NCEL has been operating (43) a multistage flash evaporator which derives its thermal energy from the jacket water and exhaust gas of a diesel generator. The evaporator is capable of producing 200 gallons per hour of potable water from sea water.

The NCEL prototype unit consists of two separate components which are housed in separate areas. The feedwater heater is mounted adjacent to the diesel generator.

The 24-stage evaporator consists of four rectangular boxes. Tests with this unit at NCEL show promise for use at Navy bases throughout the world. The Coast Guard is currently field-testing the unit on Marcus Island in the North Pacific Ocean.

The Navy permitted the University of California to test its 500 gpd reverse osmosis pilot plant (44) on sea water at Port Hueneme. The pilot plant was tested during April and May of 1962. While the tests were generally satisfactory, it was discovered that particulate matter in the sea water contaminated the membranes and resulted in a higher fraction of the salt passing through the membrane than during periods when the sea water did not appear to contain as much particulate matter.

PRIVATE COMPANIES

Several companies in California are also doing research and development work on saline water conversion. In addition, some of the large power companies have not only undertaken

development work in saline water conversion, but also use distillation processes to produce boiler quality feed water directly from sea water.

Pacific Gas and Electric Company.

This power company pioneered in the conversion of sea water for use in boilers at steam electric power plants. The original submerged tube evaporators (45,46) installed at the Morro Bay power plant are still giving good service after seven years. During 1962 they were used extensively in producing water for startup of Units 3 and 4 at Morro Bay.

In addition, the company has flash-type evaporators at its installations completed this year or currently under construction, as follows:

| | |
|----------------|-------|
| Morro Bay Unit | No. 3 |
| Morro Bay Unit | No. 4 |
| Contra Costa | No. 6 |
| Contra Costa | No. 7 |

All of the flash units are rated at 50 gpm, producing boiler quality water of no more than 1/2 ppm of total dissolved solids. The units at Morro Bay are single-stage flash units operating on full strength sea water, thereby reducing the salt concentration from approximately 3.5 percent to nearly zero.

The units at the Contra Costa plants will be two-stage flash units operating on San Joaquin River water. The salt concentration varies from 100 to 5,000 ppm, depending on the season, and will be reduced to less than 1/2 ppm regardless of the concentration of the salt in the feed.

The company also plans to use a single-stage flash evaporator to produce boiler quality water at its nuclear plant planned for Bodega Bay. Whereas the flash evaporators at Morro Bay and Contra Costa recycle the brine, the evaporator planned for Bodega Bay will use the once-through cycle (47).

Southern California Edison Company.

The company has been operating a 26-stage flash evaporator with a rated output of 100,000 gpd at its Mandalay steam station since January 1960. Details of the plant's design and operation have been reported previously (1,48,49,50,51,52).

During 1962 it was decided to experiment with pH control to prevent the formation of scale. Equipment was designed and installed that will permit acid injection. The initial tests were started in December 1962. It is hoped the use of acid to prevent scale will permit a higher economy. Caustic is used to bring the saline solution back to alkaline after the scale-forming carbonates are removed. At the higher pH the solution is not nearly as corrosive to the steel vessels.

North American Aviation.

The Rocketdyne Division of North American Aviation announced (53) in 1961 that it had designed and would build and operate a pilot plant to convert sea water to fresh water. The pilot plant was built and initial operation started in 1961 at an ocean site near Oxnard, California, on land leased from the

Southern California Edison Company at Mandalay Beach. It was operated until late in 1962 to obtain engineering data and operating experience.

The pilot plant has a capacity of 15,000-20,000 gallons per day of product water. The company expects to invest about one million dollars in research and development costs over a two-year period (53) in proving out the process.

The process eliminates conventional heat exchangers in all principal sections of the freezing process (54). It consists of four main steps: precooling the sea water feed, freezing to produce ice crystals, separating and washing the crystals from the brine, and melting the crystals to obtain fresh water. Heat recovery is practiced in all steps of the process.

The pilot plant was designed to use freezer-washer-melter equipment originally developed for the Wiegandt process (55).

In the precooling step, the sea water temperature is lowered to near freezing by passing a liquid hydrocarbon compound such as octane, directly through it. The octane is previously cooled by other process streams.

A more volatile hydrocarbon such as butane is used in the second steps to freeze the water. The ice crystals are in contact in the brine solution and must be washed. The fourth main step consists of melting the washed ice crystals by direct contact with compressed butane. The hydrocarbon compounds are recycled through the process.

The company has made considerable progress in the development of the process. This is evident from the fact that it was one of five companies that submitted bids in July 1962 to the Office of Saline Water for construction of a 250,000 gallons per day demonstration plant based on its freezing process (56).

Havens Industries.

Havens Industries is conducting private research on the reverse osmosis process of saline water conversion. This process should require a relatively small amount of energy for conversion. It can be used for brackish or sea water conversion. Since the salt removal is a function of initial salt concentration, it is more effective with brackish water.

The company is developing a membrane backing of fiberglass and resin with controlled microscopic porosity. The reverse osmosis membrane used in the tests was developed by the University of California (28,29). The membrane will permit the passage of water, but not salt when pressure greater than the osmotic pressure is applied. The fiberglass-resin backing is used as a support for the membrane.

APPENDIX A

CONVERSION ACTIVITIES OUTSIDE CALIFORNIA



TABLE OF CONTENTS

| | <u>Page</u> |
|---|-------------|
| INTRODUCTION | A-5 |
| DEMONSTRATION PLANTS | A-6 |
| Long Tube Vertical Evaporator | A-6 |
| Electrodialysis | A-10 |
| Forced-Circulation Vapor Compression | A-13 |
| ADVANCED WASTE TREATMENT RESEARCH PROGRAM | A-16 |
| RECENT COMMERCIAL PLANTS | A-17 |
| SYMPOSIUMS AND MEETINGS | A-21 |
| CURRENT CONVERSION ACTIVITIES | A-24 |
| Distillation | A-24 |
| Membranes | A-26 |
| Freezing | A-26 |
| Other | A-27 |

TABLES

Table No.

| | |
|--|------|
| A-1 Saline Water Conversion Demonstration Plants by Office of Saline Water | A-7 |
| A-2 Partial List of Recent Conversion Plants - (In Operation or Under Construction since 1960). | A-18 |

FIGURES

Figure No.

| | |
|--|------|
| A-1 Schematic Flow Diagram of the Long Tube Vertical Evaporation Process at Freeport, Texas | A-8 |
| A-2 Schematic Diagram of a Typical Electrodialysis Stack | A-11 |
| A-3 Schematic Flow Diagram of the Forced-Circulation Vapor Compression Process under Construction at Roswell, New Mexico | A-14 |



INTRODUCTION

In order to give a more complete picture of saline water conversion, some of the important activities in the field outside the State are included in this bulletin. The Office of Saline Water demonstration plants are briefly described. The Advanced Waste Treatment Research Program of the U. S. Public Health Service is discussed. In addition, a partial list of commercial conversion plants in operation or under construction since 1960, are tabulated to indicate that many areas, both domestic and foreign, are finding saline water conversion an aid in the solution to their water supply problems.

The meetings on the subject of conversion that have been held both in the United States and in other countries during the year are briefly described.

The majority of the known conversion processes have been described in the Office of Saline Water annual reports. The department also described the major processes in its Bulletin No. 93 (1). Only recent advances in some of the more promising processes have been included in this bulletin.

DEMONSTRATION PLANTS

The Office of Saline Water was directed by Public Law 85-883 to construct and operate five demonstration conversion plants. One of the five is the demonstration plant at San Diego, which was previously described in this bulletin.

Two of the plants (Freeport, Texas and Webster, South Dakota), have been in operation through the year, and one is under construction (Roswell, New Mexico). Construction of the fifth plant is planned (57) for Wrightsville Beach, North Carolina.

The capacities of the demonstration plants and other pertinent information are listed in Table A-1. Descriptions of the processes are contained in the following sections.

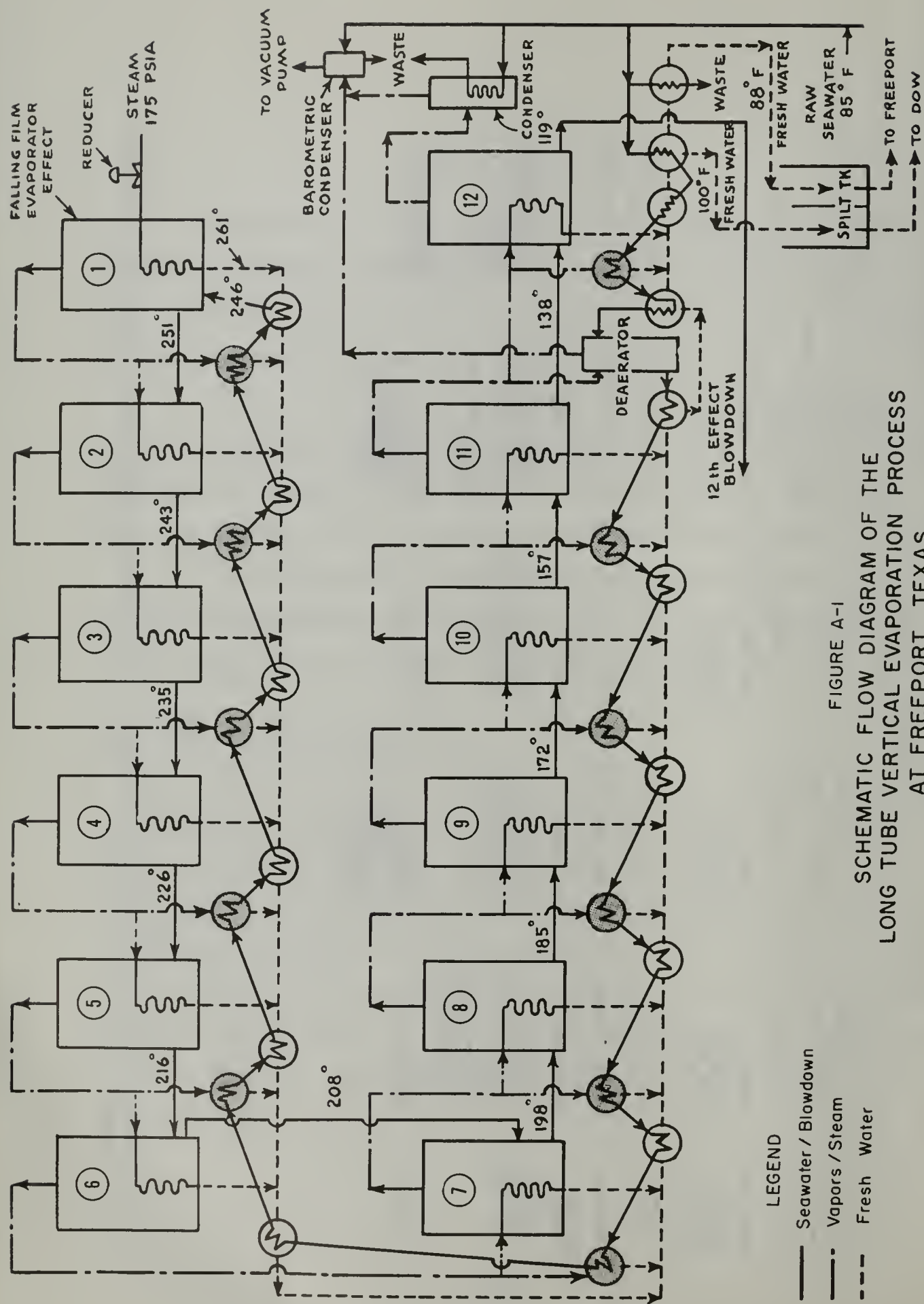
Long Tube Vertical Evaporator

The one million gallons per day demonstration plant utilizing this process is located at Freeport, Texas. The details of the construction requirements for the plant and the process conditions are contained in the bid documents (58) issued by the Office of Saline Water for the construction of the plant. In addition, details of the operation of the plant have been previously described (23,59,60,61). Only a brief description of the process is given here. A schematic flow diagram of the process is shown in Figure A-1.

TABLE A-1
SALINE WATER CONVERSION DEMONSTRATION PLANTS
OFFICE OF SALINE WATER

| Type of process | San Diego California | Freeport Texas | Webster South Dakota | Roswell New Mexico | Wrightsville Beach North Carolina |
|--|---|--|---|---|---|
| | 36-stage flash evaporator. | 12-effect LTV evaporator. | Electrodialysis | Forced-circulation vapor-compression distillation. | Freezing |
| Cost of Plant | \$1,663,246 | \$1,255,712 ¹⁾ | \$482,200 | \$1,798,000 | \$1,232,000 |
| Type of water | Sea Water | Sea Water | | | |
| Capacity | 1,000,000 gpd | 1,000,000 gpd | 250,000 gpd | 1,000,000 gpd | 200,000 gpd |
| Plant startup | Nov. 3, 1961 | April 10, 1961 | Sept. 12, 1961 | — | — |
| Dedication | March 10, 1962 | June 21, 1961 | Oct. 20, 1961 | — | — |
| Architect-Engineer | Fluor Corporation | W.L. Badger & Assoc. | Bureau of Reclamation | Catalytic Construction | Struthers Scientific & International Corp. |
| Constructor | Westinghouse-Parsons | Chicago Bridge & Iron | Asdhi-Austin | Chicago Bridge & Iron | Chemical Construction Corp. |
| Operator-Manager | Burns and Roe | Stearns-Roger | Mason-Rust | American Hydrotherm Corp. | — |
| Cooperating agencies and contributions | State of California 50% plant cost, engineering assistance San Diego Rough grading of site, access roads, 4-mile product pipeline | Dow Chemical Sells steam to plant, permits use of its sea water intake and land for site | Webster, S. D. Provided land, delivers brackish water to plant, disposes of brine. | Roswell, New Mexico Provided land, delivers brackish water, disposes of brine. State of New Mexico \$100,000 | State of North Carolina 25 acres and \$200,000 site preparation Wrightsville Beach \$10,000 |
| Product distribution | San Diego \$0.20/1,000 gal | Freeport 500,000 gpd at \$0.20/1,000 gal. Dow Chemical Company 500,000 gpd at \$0.30/1,000 gal. | Webster \$0.30/1,000 gal. | Roswell \$0.60/1,000 gal. first 250,000 gal. \$0.40/1,000 gal for balance. | Wrightsville Beach \$0.20/1,000 gal. |

1) Did not include boiler and appurtenances or the usual sea water intake facilities. An existing sea water line and canal operated by Dow Chemical was used to provide the conversion plant with sea water.



In this process, twelve evaporators called effects are connected in series. The sea water is first heated in heat exchangers that are used to recover heat from the brine and product. The evaporation of the sea water is started in the first effect, which is at the highest temperature. In this effect steam is admitted into the shell of the evaporator. The steam condensing on the tubes causes some of the sea water to boil as it flows down the inside surface of the tubes. The vapor evolved from the boiling sea water now called brine is disengaged from the brine and is conducted to the shellside of the second effect, which is at a lower pressure and temperature. The brine is also pumped to the second effect tubes. The vapor condenses on the outside surface of the tubes, giving up its heat of condensation to the brine inside the tubes.

In the second effect additional water is boiled away from the brine. This procedure of heating and boiling is repeated in each effect until the last or lowest temperature effect is reached. The brine remaining at this point is pumped to waste. It contains about four times the amount of salt as the original feed sea water.

During the year the Freeport plant has been controlling scale by the addition of sulfuric acid. The addition of acid decomposes the carbonate and prevents both calcium carbonate and magnesium hydroxide scale. Calcium sulfate scale is prevented by operating at conditions of temperature and salt concentration in which calcium sulfate is not saturated.

The corrosion problems (62) encountered the previous year with the steel tubes have been overcome by replacing with tubes of material more resistant to the conditions encountered in the evaporators and heat exchangers.

In effects 10, 11, and 12, modified distributor plates were installed and the pumps associated with these effects were modified (23). Also the main feed pumps between the deaerator and evaporators have been modified (23).

Electrodialysis

The 250,000 gallons per day demonstration plant utilizing this process is located at Webster, South Dakota. The details for the construction of the plant and the process conditions are contained in the bid documents (63) issued by the Office of Saline Water for the construction of the plant. In addition, the operation of the plant has been previously described (23,64,65).

In this process, the salt is removed from the water by the use of membranes. The raw water is pretreated to remove iron and manganese before it is fed to the electrodialysis equipment, which is referred to as a stack. A typical stack is shown in Figure A-2. The pretreated water is divided into three streams termed dilute, concentration, and electrode stream. Each stream is adjusted to the required flow, pH, and chemical balance.

This demonstration plant contains 217 membrane cell pairs in a stack. Four such stacks are used in series. The water is fed to the top of the concentration cell and to the bottom of

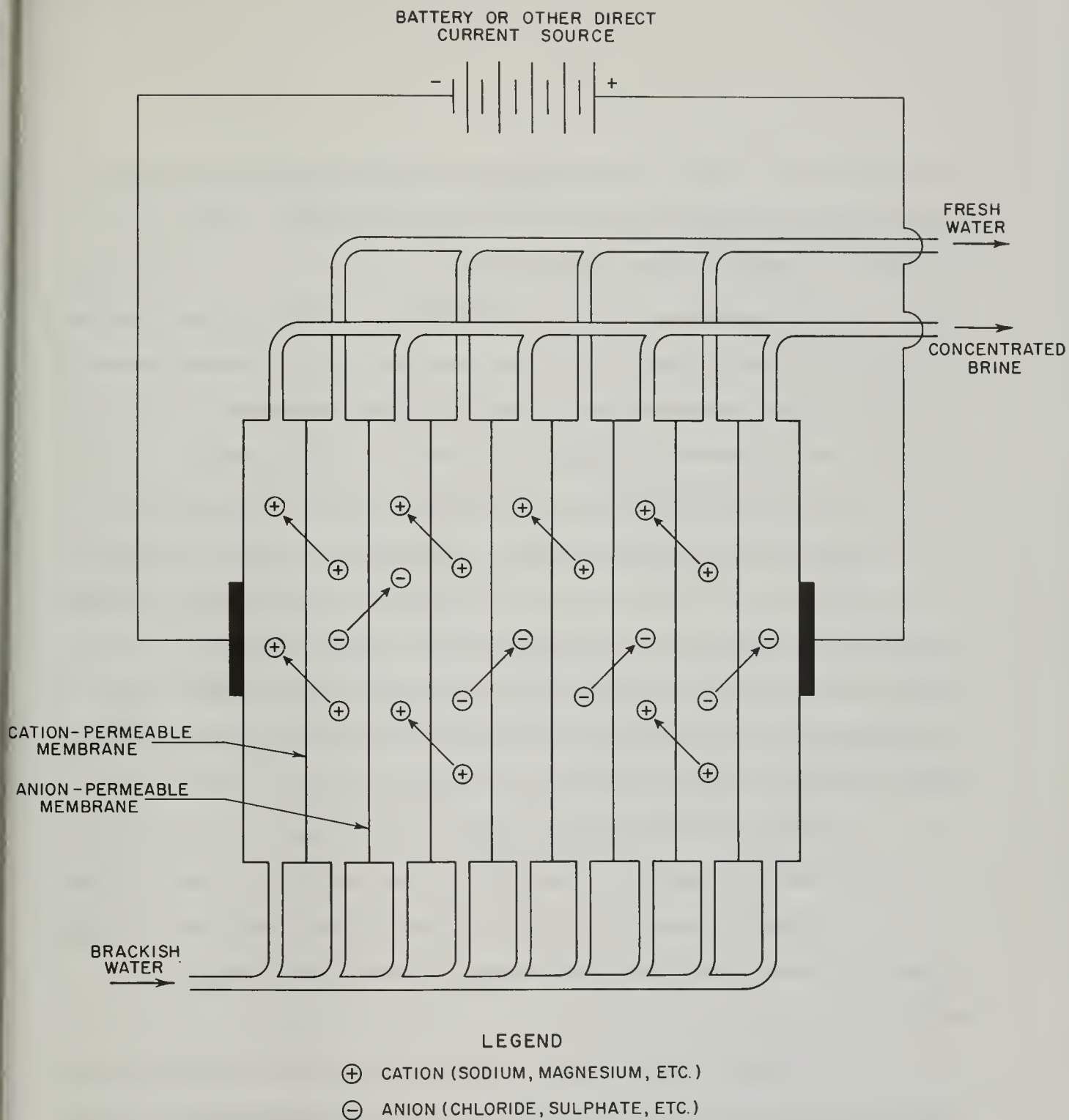


FIGURE A-2
A SCHEMATIC DIAGRAM OF
A TYPICAL ELECTRODIALYSIS STACK

the dilute cell. The direct current applied across the stack causes the salt ions to move toward the respective electrodes located at opposite ends of the stack.

The membranes are permselective in that a given membrane will either pass anions or cations, but not both. The movement of ions is thus interrupted by the selective membranes. On one side of the concentration cell is a membrane which stops the anions such as chloride, and on the other side is a membrane which stops cations such as sodium. The cells adjacent to the concentration cell are losing ions and thus the solution becomes less salty. The dilute stream passes in series through the four stacks losing 40 to 50 percent of its salt in each stack. The dilute stream leaving the final stack becomes the product water after any posttreatment required for pH or chemical control.

The electrodialysis plant was shut down in October 1962 for a detailed inspection of operating components following a full year of successful operation (66). During the first year of operation the plant produced approximately 75 million gallons of water.

The major areas where improvements (23) were made since the original design were in elimination of air entrainment in the water which caused operating difficulties in the stack, in adjustment in chemical additives to prevent scale, and in revision of the rinse stream to conserve acid.

Forced-Circulation Vapor Compression

The one million gallons per day demonstration plant utilizing this process was under construction at Roswell, New Mexico at the end of 1962. The details of the construction requirements for the plant and the process conditions specified are contained in the bid documents (67) issued by the Office of Saline Water for the construction and initial operation of the plant. The principle of this process has been previously described in the literature (68). A schematic flow diagram of the process is shown in Figure A-3.

In this plant three effects will be operated in series with a single vapor-compression cycle operating over the total temperature range. The feed brine is treated to remove scale-forming chemicals and preheated by exchange with the product water and blowdown. The brine is then introduced into the first evaporator effect, which is at the highest temperature. At this point it is mixed with the stream being circulated (69,70).

The steam from the vapor compressor condenses in the first effect brine heater and raises the temperature of the brine which is under forced circulation. Boiling is suppressed in the heater by the hydrostatic head. When the brine enters the evaporator flashing takes place as the pressure is reduced.

The partially concentrated brine flows to the second effect where it is mixed with the circulating stream. The vapor evolved in the first effect is used to heat the brine in the second effect. The same process is repeated in the third effect.

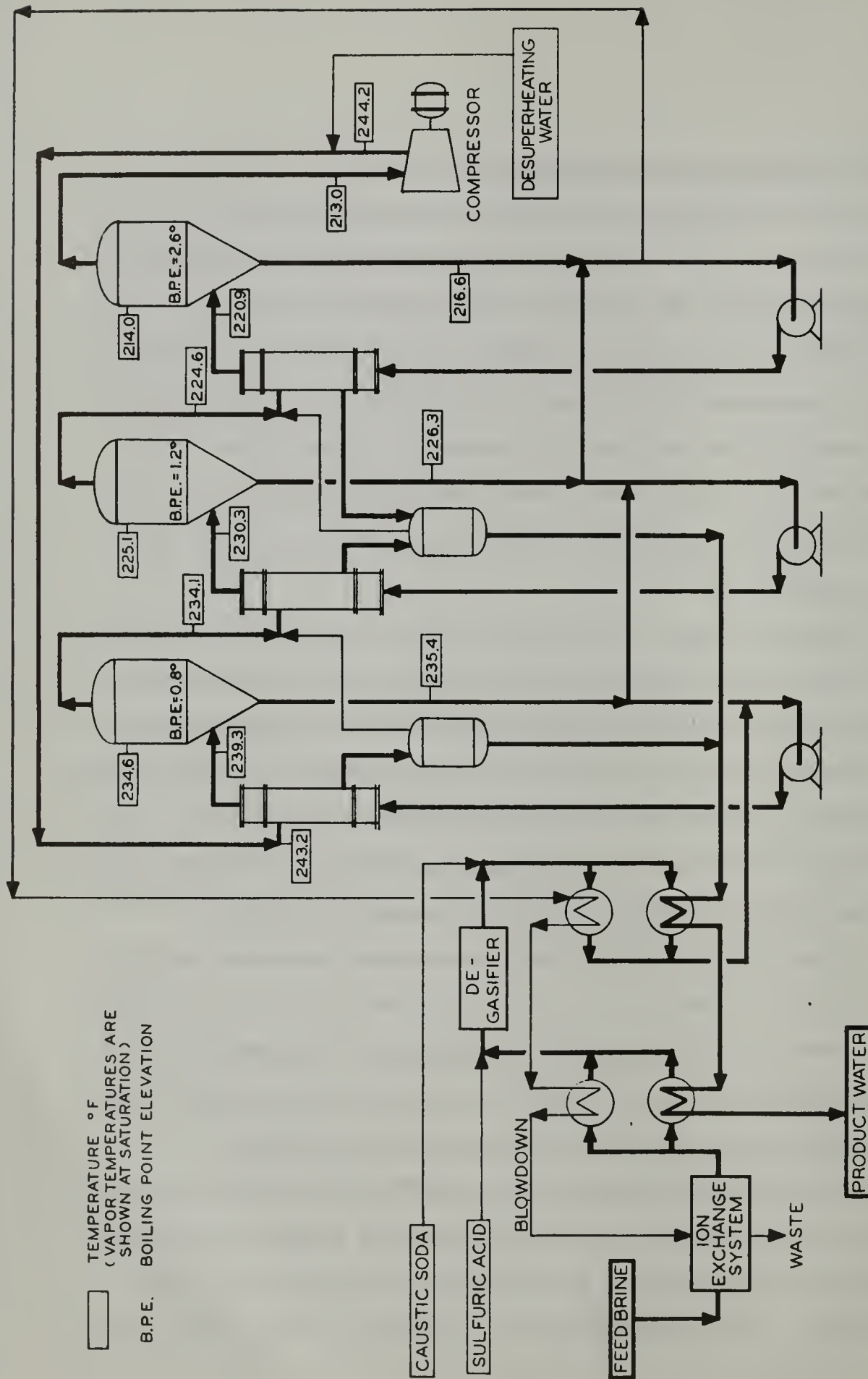


FIGURE A-3
SCHEMATIC FLOW DIAGRAM OF THE
FORCED CIRCULATION VAPOR COMPRESSION PROCESS UNDER CONSTRUCTION
AT ROSWELL, NEW MEXICO
(TYPICAL OPERATING CONDITIONS)

The brine leaving the third effect is discharged to waste. The vapor is sent to the vapor compressor which raises the steam pressure to the value required in the first effect evaporator.

The flashed vapor in each evaporator after condensation and cooling becomes the product.

The construction contract was awarded on April 6, 1962. Construction is scheduled for completion in one year (71). Ground-breaking (72) ceremonies were held July 10, 1962.

ADVANCED WASTE TREATMENT RESEARCH PROGRAM

This Advanced Waste Treatment Research program of the U. S. Public Health Service has two objectives; one is to alleviate the growing pollution problem and the other is to remove dissolved materials from waste water to make it suitable for reuse.

The dissolved materials of interest in this program are those resistant to or totally unaffected by the most modern conventional water and waste treatment processes. Such materials are referred to as refractory contaminants.

Among the processes being considered for removal of organic or inorganic dissolved materials are the following:

- Adsorption
- Electrodialysis
- Evaporation
- Extraction
- Emulsion Separation
- Foam Fractionation
- Freezing
- Oxidation
- Ion Exchange
- Electrochemical Degradation

Two reports have been issued by the program (73,74). During 1962 the program did not sponsor any contract research in the State. However, several proposals from firms located in California are under consideration.

RECENT COMMERCIAL PLANTS

In order to indicate the current use of conversion equipment, a partial list of plants initially operated since 1960, or currently under construction, are listed in Table A-2. As can be seen, the largest capacity plants are located in foreign countries. A majority of the smaller capacity plants use the electrodialysis process to convert brackish water into potable water.

TABLE A-2
PARTIAL LIST OF RECENT CONVERSION PLANTS
(IN OPERATION OR UNDER CONST. SINCE 1960)

| LOCATION OF PLANT | DESIGNER OR MANUFACTURER | START OF OPERATION | TYPE OF PLANT | SIZE OF UNIT GPH | FEED PPM |
|---------------------------------|--------------------------|--------------------|------------------|------------------|-----------|
| A. UNITED STATES | | | | | |
| BUCKEYE, ARIZ. | IONICS | 1962 | ELECTRODIALYSIS | 650,000 | 2,200 |
| WINSLOW, (USAF), ARIZ. | IONICS | 1960 | ELECTRODIALYSIS | 35,000 | 1,700 |
| YUMA, (USAF), ARIZ. | AQUA-CHEM | 1962 | ELECTRODIALYSIS | 1,200 | -- |
| OXNARD, CALIF. | AQUA-CHEM | 1960 | MULTISTAGE FLASH | 100,000 | SEA WATER |
| HANNA CITY, ILLINOIS | IONICS | 1960 | ELECTRODIALYSIS | 70,000 | 1,700 |
| HAYRE (USAF #2), MONT. | IONICS | 1960 | ELECTRODIALYSIS | 56,000 | 5,400 |
| WALKER AFB, NEW MEXICO | IONICS | 1961 | ELECTRODIALYSIS | 65,000 | 5,010 |
| WALKER AFB, NEW MEXICO | IONICS | 1961 | ELECTRODIALYSIS | 43,000 | 1,528 |
| WALKER AFB, NEW MEXICO | IONICS | 1961 | ELECTRODIALYSIS | 21,000 | 2,180 |
| WALKER AFB, NEW MEXICO | IONICS | 1961 | ELECTRODIALYSIS | 21,000 | 2,160 |
| WALKER AFB, NEW MEXICO | IONICS | 1961 | ELECTRODIALYSIS | 21,000 | 2,600 |
| WALKER AFB, NEW MEXICO | IONICS | 1961 | ELECTRODIALYSIS | 21,000 | 1,362 |
| WALKER AFB, NEW MEXICO | IONICS | 1961 | ELECTRODIALYSIS | 21,000 | 872 |
| FORTUNA AFB, N.D. | IONICS | 1961 | ELECTRODIALYSIS | 44,500 | 2,088 |
| ALTUS AFB, OKLA. | IONICS | 1961 | ELECTRODIALYSIS | 21,000 | 5,322 |
| ELLSWORTH AFB, S.D. | IONICS | 1961 | ELECTRODIALYSIS | 86,000 | 796 |
| ELLSWORTH AFB, S.D. | IONICS | 1961 | ELECTRODIALYSIS | 86,000 | 407 |
| ELLSWORTH AFB, S.D. | IONICS | 1961 | ELECTRODIALYSIS | 86,000 | 2,114 |
| PICKSTON (USAF), S.D. | AQUA-CHEM | 1961 | ELECTRODIALYSIS | 5,625 | -- |
| B. OUTSIDE UNITED STATES | | | | | |
| ANTARCTICA, McMurdo Sound | AQUA-CHEM | UNDER CONST. | MULTISTAGE FLASH | 14,400 | SEA WATER |

TABLE A-2 (CONTINUED)

| LOCATION OF PLANT | DESIGNER OR MANUFACTURER | START OF OPERATION | TYPE OF PLANT | SIZE OF UNIT QPD | FEED PPM |
|---------------------------|--------------------------|--------------------|------------------|------------------|-----------|
| TRUCIAL OMAN ABU QANDI | RICHARDSONS, WESTGARTH | 1960 | MULTISTAGE FLASH | 17,200 | SEA WATER |
| ADEN | IONICS | 1961 | ELECTRODIALYSIS | 6,000 | 1,380 |
| NASSAU BAHAMA ISLANDS | G & J WEIR | 1960 | SUBMERGED TUBE | 1,200,000 | SEA WATER |
| BAHRAIN | IONICS | 1961 | ELECTRODIALYSIS | 3,000 | 3,200 |
| BAHRAIN | IONICS | 1961 | ELECTRODIALYSIS | 6,000 | 3,500 |
| BAHRAIN | IONICS | 1961 | ELECTRODIALYSIS | 6,000 | 3,200 |
| ISRAEL EILAT | BALDWIN-LIMA-HAMILTON | UNDER CONST. | MULTISTAGE FLASH | 1,000,000 | SEA WATER |
| EILAT | FAIRBANKS-WHITNEY | UNDER CONST. | FREEZING | 250,000 | SEA WATER |
| ITALY - TARANTO | AQUA-CHEM | UNDER CONST. | MULTISTAGE FLASH | 1,200,000 | SEA WATER |
| - PALERMO | IONICS | 1962 | ELECTRODIALYSIS | 6,000 | 2,300 |
| IRAN | IONICS | 1962 | ELECTRODIALYSIS | 12,000 | 2,900 |
| KUWAIT | WESTINGHOUSE | 1961 | MULTISTAGE FLASH | 500,000 | SEA WATER |
| KUWAIT | IONICS | 1962 | ELECTRODIALYSIS | 240,000 | 4,000 |
| LIBYA - OASIS OIL CO. | IONICS | 1960 | ELECTRODIALYSIS | 7,800 | 4,900 |
| - GULF OIL CO. | IONICS | 1960 | ELECTRODIALYSIS | 6,000 | 1,700 |
| - R.A.F. (EL ADEM) | IONICS | 1960 | ELECTRODIALYSIS | 10,000 | 3,980 |
| - TOBRUK | IONICS | 1960 | ELECTRODIALYSIS | 5,000 | 4,000 |
| - SANTA FE DRILLING CO. | IONICS | 1960 | ELECTRODIALYSIS | 6,000 | 1,700 |
| - FORENCO DRILLING CO. | IONICS | 1960 | ELECTRODIALYSIS | MOBILE | |
| - AGIP MINERARIA | IONICS | 1961 | ELECTRODIALYSIS | 10,000 | 5,300 |
| - ESSO | IONICS | 1961 | ELECTRODIALYSIS | 4,000 | 3,780 |
| QATAR | RICHARDSONS, WESTGARTH | 1962 | MULTISTAGE FLASH | 900,000 | SEA WATER |

TABLE A-2 (CONTINUED)

| LOCATION OF PLANT | DESIGNER OR MANUFACTURER | START OF OPERATION | TYPE OF PLANT | SIZE OF UNIT GPH | FEED PPM |
|--|--------------------------|--------------------|------------------------|------------------|-----------|
| QATAR | RICHARDSONS, WESTGARTH | 1962 | MULTISTAGE FLASH | 900,000 | SEA WATER |
| SAUDI ARABIA AR. AMER. OIL CO. | IONICS | 1961 | ELECTRODIALYSIS | 115,000 | 2,700 |
| SPANISH SAHARA DRILLING & EXPLORATION Co. | IONICS | 1961 | ELECTRODIALYSIS | MOBILE UNIT | -- |
| SONPETROL | IONICS | 1962 | ELECTRODIALYSIS | MOBILE UNIT | -- |
| DEILMAN BERGMAN G.M.B.H. | IONICS | 1962 | ELECTRODIALYSIS | 6,000 | 5,000 |
| PHILIPPINES U. S. NAVY | IONICS | 1962 | ELECTRODIALYSIS | 6,000 | 2,200 |
| TUNISIA ZARGIS | IONICS | 1961 | ELECTRODIALYSIS | 6,600 | 6,300 |
| VIRGIN ISLANDS ST. THOMAS | AQUA-CHEM | 1962 | MULTISTAGE FLASH EVAP. | 275,000 | SEA WATER |
| WEST INDIES ANTIGUA | IONICS | 1962 | ELECTRODIALYSIS | 1,400 | 1,642 |

SYMPOSIUMS AND MEETINGS

An increasing number of meetings are being devoted to the general subject of removal of dissolved materials from water. The subjects covered include sea and brackish water conversion and waste water reclamation. Some of the more general meetings are briefly described. In most cases, the papers presented at the meetings have been or will be published.

At the 1962 spring meeting of the American Chemical Society in Washington, D. C., the Division of Water and Waste Chemistry organized a symposium on saline water conversion. Papers for the full-day program covered such topics as the use of osmotic membranes, the minimizing of scale formation, the design of large electrodialysis equipment, factors affecting the cost of electro-dialytic demineralization, development of freezing processes, new agents for the hydrate process, the effect of vibration on heat transfer and scale formation, phosphate precipitation of minerals from sea water, and flash evaporation utilizing solar energy. The American Chemical Society plans to publish the papers in 1963 in its ADVANCES IN CHEMISTRY series. Extended abstracts of the papers were published by the Division of Water and Waste Chemistry (75).

On March 28, 1962, the Office of Saline Water held a conference on saline water conversion in Washington, D. C. Papers were presented dealing with basic research problems, with applied research progress, and with the operation of the first three

demonstration conversion plants. The proceedings of the meeting have been published (23).

A seminar on advanced waste treatment research was held in Cincinnati, Ohio, on May 15-16, 1962, under the auspices of the Robert A. Taft Sanitary Engineering Center. This research is an activity of the Basic and Applied Sciences Branch, Division of Water Supply and Pollution Control, Department of Health, Education, and Welfare. Much of the basic research work for the activity is performed under contract by independent agencies outside the federal government.

The purpose of the seminar was to summarize the work of these contractors, and to supply a forum for the interchange of information and ideas. Processes discussed at the meeting (76) for removal of dissolved materials from waste water included adsorption, foam separation, freezing, electrodialysis, ion exchange and distillation.

The first European symposium on fresh water from the sea was held at Athens, Greece, from May 31 to June 4, 1962. This meeting was organized by the European Federation of Chemical Engineers. Of the fifty-four lectures presented, twenty were from representatives of United States Industries or universities. Most of the other papers were presented by leaders in the field of saline water conversion from France, Holland, India, Israel, Japan, United Kingdom, West Germany, and Yugoslavia. Papers presented at the symposium have been published (77).

An increasing number of papers on saline water conversion are appearing on programs prepared for regular national meetings of scientific and engineering societies. In addition, the Los Angeles Chamber of Commerce made a report on saline water conversion at a half-day meeting in Los Angeles on December 7, 1962. The study was made in conjunction with the chamber's overall study titled "Destination '70 -- a Program for Your Future." The report has been published (78).

CURRENT CONVERSION ACTIVITIES

Investigations on saline water conversion undertaken by the University of California, sponsored by the Office of Saline Water, conducted by other public agencies and done by private industry, cover a wide scope from studies of the fundamental properties of water and saline solutions to the development of hardware for commercially proven processes.

The information obtained in some of the fundamental studies may be applicable to distillation, membrane, freezing, or other processes. In the case of studies concerned with a specific phenomena, the results are generally applicable to only one type of conversion process.

A brief account of some of this year's highlights is included. More detailed information on any specific subject may be obtained from the publications listed in the bibliography.*

Distillation

Fundamental studies are being made on the material and energy transfer through noncondensable gases, the properties of water in the state of evaporation and boiling mechanism.

The mechanism of scale formation is under intensive laboratory investigation. Once the mechanism is better understood,

*Especially reports by the Office of Saline Water and the University of California.

it may be possible to develop improved ways to reduce scaling tendency in distillation equipment.

Methods currently being developed for prevention of scale include removal of scale-forming materials by ion exchange or acid injection, and circulation of a sludge of scale-forming materials. In the latter scheme, the scale-forming chemicals tend to precipitate preferentially on the sludge, rather than on the metallic heat transfer surface.

Another approach in avoiding scale on heat transfer surfaces is to use an immiscible liquid for transfer of heat, thereby eliminating the need for a metallic heat transfer surface. Laboratory and pilot plant testing are being employed in the investigation.

Continuing studies are being made on methods to improve heat transfer through metallic surfaces and ways to mitigate corrosion in equipment. Thin films and vibrations have been tested this year to improve heat transfer. Dropwise promoters continue to be tested. Testing of materials of construction is being done at the Office of Saline Water Demonstration plants. Fundamental studies of corrosion in saline solutions are being conducted at several laboratories.

Hardware for commercial processes is being evaluated and improved by many works in the field.

Solar energy applications continue to be studied. The use of large ponds for conversion and salt recovery is under study. Various multiple-effect humidity cycles are being investigated.

Membranes

The potential of membranes for the production of potable water at relatively low energy consumption is attractive. Much work is being done on the transfer of ions and water through membranes.

The studies involved with ion transfer are largely concerned with improvement in the electrodialysis process. Improvements in properties of membranes have been given much attention.

The condition under which polarization occurs is being investigated. Since polarization reduces efficiency, the purpose of the work is to improve means of avoiding the phenomenon.

Testing and improvement in the electrodialysis apparatus was also continued during the year.

Several investigations are under way on various aspects of the mechanism of water transfer through membranes aimed at the development of a reverse osmosis process. Some of the studies involved membrane improvement. Others are more fundamental investigations aimed at an elucidation of the phenomena involved in the transfer of water through the membrane.

Freezing

The freezing processes have been given increased attention. Processes involving the direct freezing of water to ice and the formation of a hydrate of an organic molecule (for example, propane), are being developed.

Fundamental laboratory work involved with clathrate freezing is in progress. Methods of crystal growth are under investigation as a means of improving ice-brine separation, which has been one of the more difficult technical problems involved with the process.

The majority of the freezing processes use a direct freezing cycle. Several organic materials have been tested for this application.

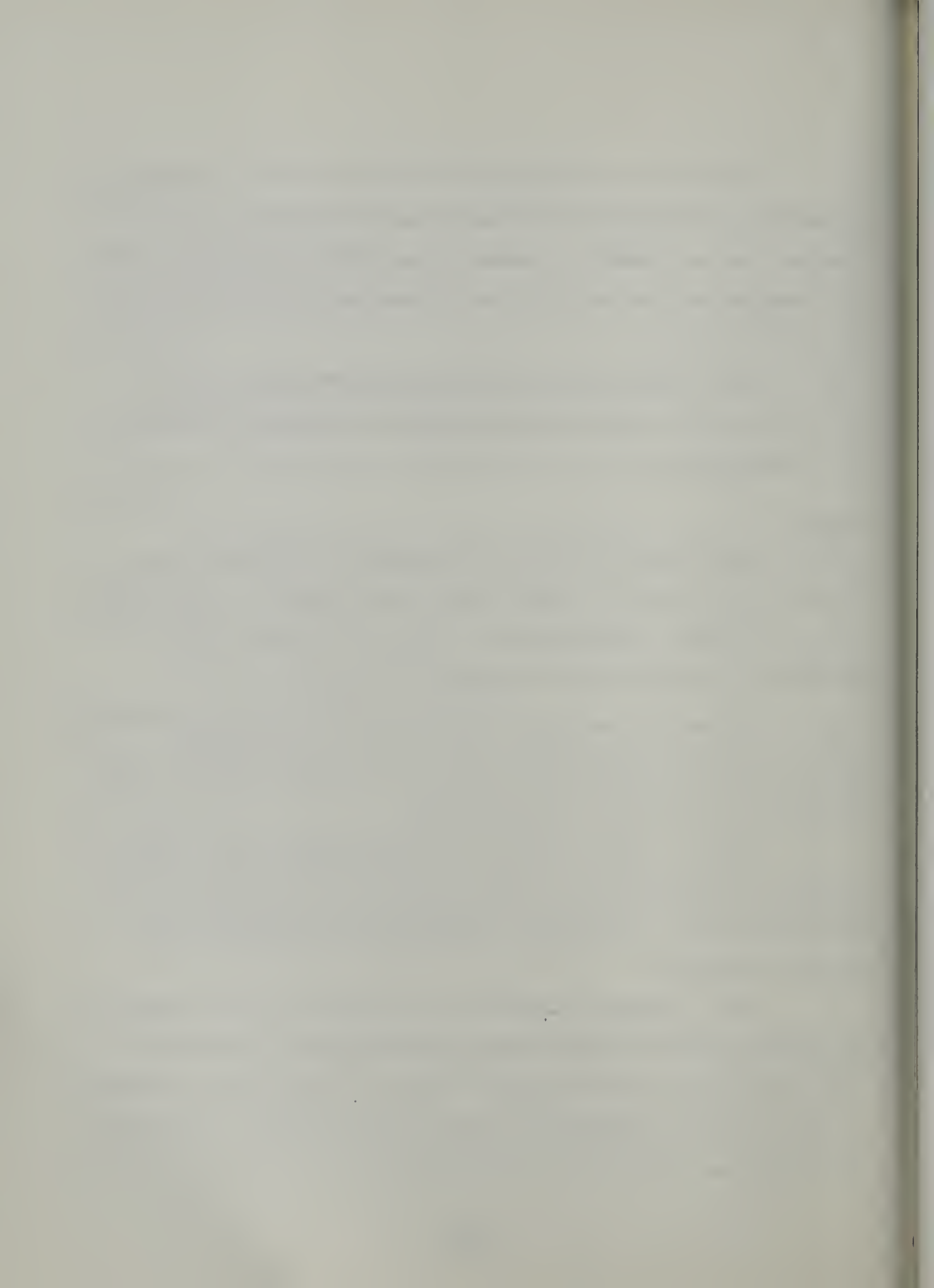
Other

Many other processes and phenomena are under study. Some of the fundamental work include measurements of basic properties of water, thermodynamics of saline solutions, molal entropies of ions and salt transport of plants.

Extraction and use of by-products in conversion processes have been given increased attention. The production of a high analysis fertilizer has been proposed.

Work is being done with chelating agents (for scale control), absorptivity on porous conductors, and solvation of polyvalent ions in an effort to develop more economical conversion processes.

Ion exchange regeneration and applications for pre-treatment to remove scale-forming materials have been studied in the laboratory and pilot plant. Tests are planned at the Office of Saline Water, Roswell, New Mexico, demonstration plant once the plant has been placed in operation.



APPENDIX B

APPLICATION OF SOLAR ENERGY
TO CONVERSION IN CALIFORNIA

TABLE OF CONTENTS

| | <u>Page</u> |
|-------------------------------------|-------------|
| INTRODUCTION | B-5 |
| DISCUSSION | B-5 |
| PROCESS DESCRIPTION | B-7 |
| SOLAR COLLECTOR SELECTION | B-12 |
| SOLAR ENERGY COST | B-27 |
| EVAPORATOR COST | B-33 |
| WATER COST | B-33 |
| RECOMMENDATIONS | B-33 |
| SUMMARY & CONCLUSIONS | B-39 |

Table No.

| | | |
|------|--|------|
| B- 1 | Summary of Process Conditions | B-13 |
| B- 2 | Hourly Summary of Direct and Diffuse Radiation . . . | B-17 |
| B- 3 | Transmittance-Absorption Product for Tedlar and Blackened Collector Bottom | B-20 |
| B- 4 | Solution of Equation 2 (Heat Loss in Btu) | B-24 |
| B- 5 | Installed Cost of Solar Collector | B-28 |
| B- 6 | Cost of Bottom Covering | B-28 |
| B- 7 | Installed Cost of Tedlar Glazing | B-29 |
| B- 8 | Total Daily Operating Cost of Solar Collector | B-29 |
| B- 9 | Cost of Collected Solar Energy | B-31 |
| B-10 | Summary of Flash Evaporator Heat and Flow Conditions for Several Terminal Temperature Differences . . . | B-34 |
| B-11 | Flash Evaporator Capital Cost and Power Requirements | B-34 |
| B-12 | Flash Evaporator Operating Costs | B-37 |

TABLE OF CONTENTS (Cont'd)

| <u>Figure No.</u> | | <u>Page</u> |
|-------------------|---|-------------|
| B-1 | Schematic Flow Diagram | B-8 |
| B-2 | Average Hourly Solar Radiation on a Horizontal Surface August through December . . . | B-16 |
| B-3 | Transmittance-Absorption Product for Tedlar Glazing and Black Bottom Surface with Respect to the Angle of Incidence | B-21 |
| B-4 | Net Heat Gain for Five Layers of Tedlar Glazing . . | B-25 |
| B-5 | Variation in Net Heat Gain for Five Layers of Tedlar Glazing by Month | B-26 |
| B-6 | Domains of Glazing Layers for Solar Heat Cost . . . | B-32 |
| B-7 | Variation in Flash Evaporator Output With Brine Feed Temperature | B-35 |
| B-8 | Variation in Flash Evaporator Heat Requirements with Brine Feed Temperature | B-36 |
| B-9 | Water Cost Versus Brine Temperature | B-38 |

INTRODUCTION

In the application of solar energy to saline water conversion the combination of a solar heat collector with a process that is capable of energy reuse may be economically more attractive than direct solar distillation. The multistage flash evaporation process can more efficiently utilize the relatively low temperature saline water produced in a flat-plate solar heat collector than most other conversion processes. A combination plant was designed to produce annually 345×10^7 gallons of water when collecting slightly more than four trillion Btu of heat.

A coastal location in Southern California was assumed for the site of this combination plant; consequently, solar insolation data, as well as other meteorological data for that area, were used in making calculations for the solar heat collector. The results, however, should be generally applicable to other geographical areas if corrections are applied for the amount of insolation received.

DISCUSSION

The primary purpose of this study was to optimize the cost of water produced in a multistage flash evaporator supplied by brine heated in a solar heat collector. It was, therefore, not possible to select both the plant capacity and the solar collector area and still permit optimization. In addition, the brine temperature limitation would be set by an economic evaluation of

both the multistage flash evaporator and the solar heat collector. Evaporator capital and operating cost estimates from a previous study (79) were used extensively in this evaluation.

Because the plant output varies with the time of year, it was necessary to determine the output on some logical basis. The basis used was the monthly average of the insolation received at a site along the Southern California Coast. With the available monthly average insolation known, it was possible to determine the net heat that could be captured by a solar heat collector with a given number of glazing layers. In addition, the cost of installing the solar collector was estimated. With the capital cost estimated and the net heat captured calculated, the relative cost of the solar energy on a monthly average basis for several selected brine temperatures could be determined. The plant could then be optimized for a given assumed brine temperature and assumed stage terminal temperature difference in the flash evaporator. Although we are interested in the average cost of the water on an annual basis, it was first necessary to determine the approximate plant size. By optimizing the water cost by month for the minimum solar energy cost for several selected brine temperatures, it was possible to determine the point of minimum operating cost for the several assumed evaporator plant capacities. Once this had been determined, it was then possible to calculate the area of solar collector required for each condition.

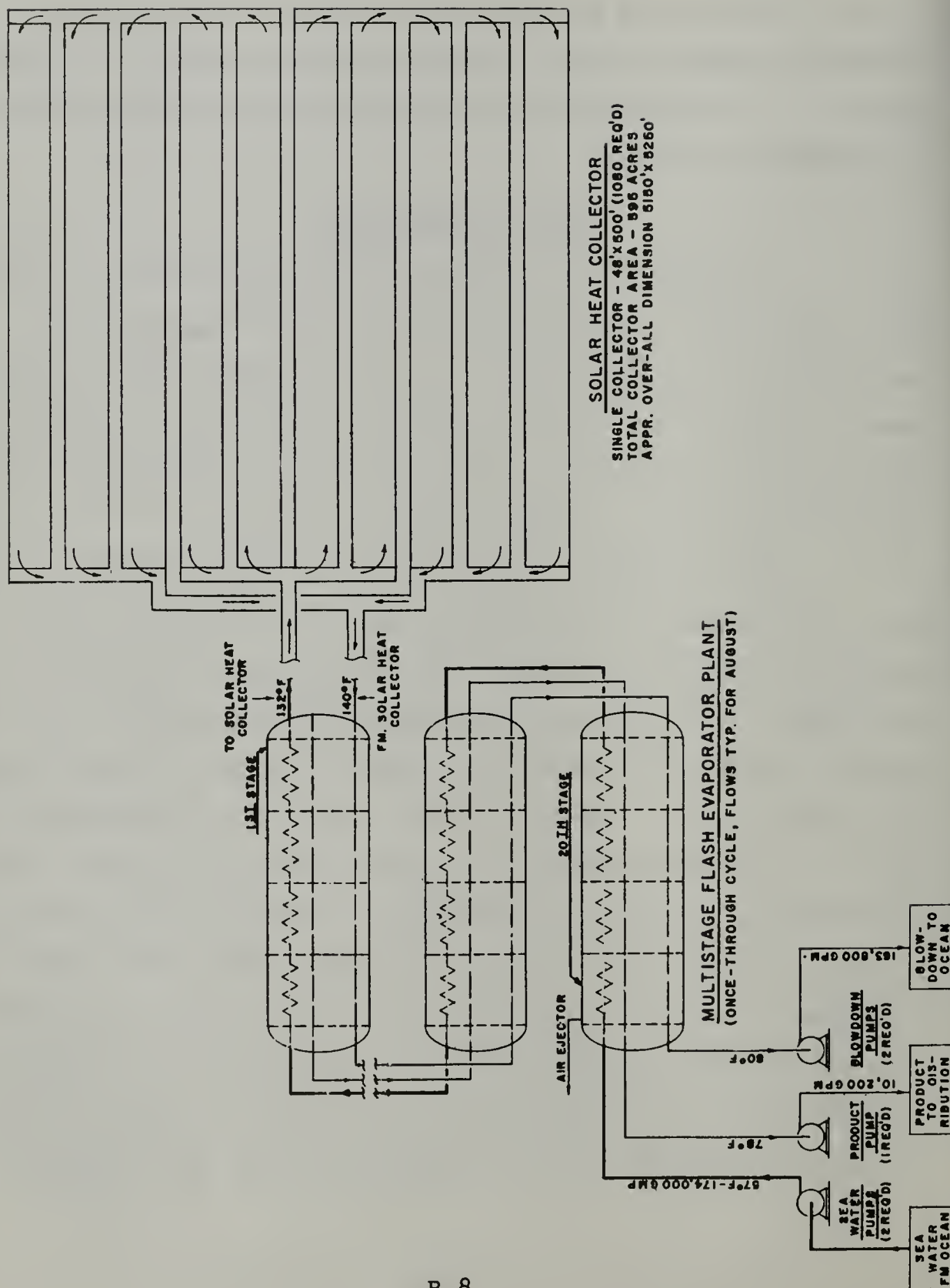
As might be expected, the optimization was heavily weighed in terms of summer operation when insolation is at a maximum and for the higher brine temperatures when the plant output is relatively greater.

PROCESS DESCRIPTION

A schematic flow diagram of the plant is shown in Figure B-1. This figure represents the general flow diagram of the multistage flash evaporation process and the solar heat collector system. The process conditions shown on the diagram are typical for operation with a brine temperature of 140°F. as would be the case during the months of May, June, and August.

The sea water is pumped from the inlet sump to the evaporator plant where it flows through the tubes of the 20-stage evaporator. As the sea water flows through the stages of the evaporator, it is gradually heated from the temperature of the ocean to 132°F. as a result of the vapor condensing on the outside of the tubes. As it leaves the first stage of the evaporator at 132°F., it is discharged into a canal system and allowed to flow by gravity to the solar heat collector. The sea water then flows through the solar heat collector as shown in Figure B-1. This flow arrangement down the entire length and return permits the flow to take place without piping and with a minimum amount of channels. The sea water travels approximately two miles and requires about 36 hours to complete its flow through the solar heat collector.

FIGURE B-1
SCHEMATIC FLOW DIAGRAM
(3°F. TERMINAL TEMPERATURE DIFFERENCE)



The entire flow is by gravity. As shown in Figure B-1, during August the sea water would be returned to the evaporator at a temperature of 140°F. It would be introduced into the shellside of the first stage of the evaporator vessel which is under a partial vacuum. The flashing process would start at this point.

The heated sea water enters the shellside of the first stage with 33,600 ppm of salt. Since some of the water would be flashed off in each stage, by the time the sea water reaches the lowest temperature stage the salt concentration would be increased by approximately six percent. The sea water flows through the plant at a rate of 174,000 gpm. Two pumps would be required in the sea water sump to supply this volumetric flow at the head required. Approximately 164,000 gpm would be returned to the ocean as blowdown. The difference of about 10,000 gpm is the product which is also pumped from the system and delivered to the distribution system.

The flow system just described is known as a "once-through system." It is customary to employ recycle when operating at higher brine temperatures. In a recycle system the brine is recirculated through the system several times and the blowdown concentration is perhaps twice that of normal sea water. The primary reason for employing recycle is to reduce the cost of the scale control chemicals that are required to prevent scale when operating at higher temperature. In the combination with the solar heat collector the economics are different. The economic life of the

plastic glazing material occurs when operating at relatively lower temperatures. Also, operation much above a 150°F. brine temperature would require the addition of chemicals for scale control. In order for higher brine temperatures to be an advantageous means of operation, it would be necessary to substantially increase the temperature of the solar collector operation to more than compensate for the cost of the scale control chemicals. With the increased heat loss at higher temperatures and the reduced life of the glazing, higher temperature operation of the solar collector is not economically justified.

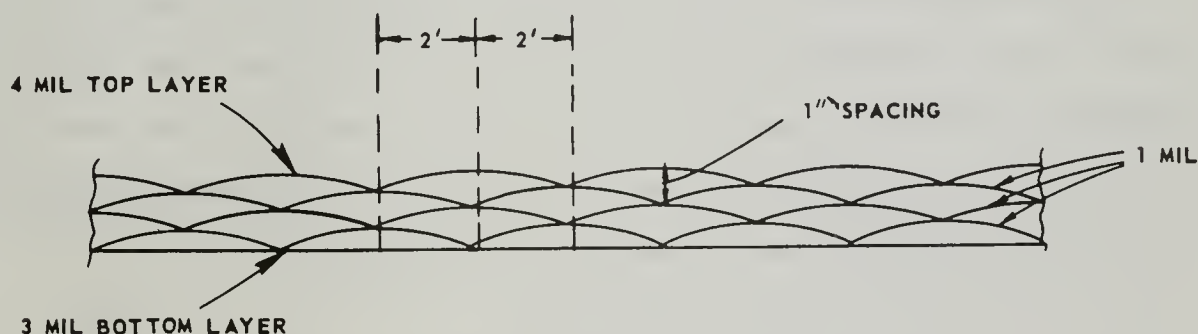
The tubeside brine is discharged from the first stage of the evaporator vessel into a concrete-lined and covered channel which permits the brine to flow into the solar heat collector. The solar heat collector is composed of concrete curbing on 48-foot centers in one direction and 500-foot centers in the other direction. The collector is covered with multiple layers of glazing. The sea water flows parallel to the 48-foot sides, that is, the flow path is along the 500-foot dimension. These 500-foot length curbings represent a common wall from one collector to the next. Slots in these curbs permit the brine to flow continuously through the entire mile of collector before reversing direction. Once the brine has reached the end of the solar collector away from the evaporator, it flows into a concrete-lined channel and is diverted back through another series of collectors emerging finally into a concrete-lined channel at the evaporator end of the collector.

The heated sea water then returns to the evaporator plant and is introduced into the shellside of the first stage of the evaporator through a siphon leg. No pump is required at this point in the system. Actually, as can be seen from Figure B-1, pumps are required to move the sea water through the tubes, and to remove the blowdown and the product from the last stage. No other major pumps are required in the operation of the once-through cycle.

For the multiple-layer glazing covering the thickness of the glazing was selected as follows:

| | |
|---------------|--------|
| Top layer | 4 mils |
| Inside layers | 1 mil |
| Bottom layer | 3 mils |

The bottom layer floats on the surface of the sea water. A cross-section of a five-layer glazing covering in the inflated condition is shown below:



As indicated in the sketch, the layers are heat-sealed every four feet and air pressure is used to hold the layers apart. The air space between layers imparts desirable heat insulation properties to the covering. The primary purpose of the bottom

floating layer is to prevent evaporation and condensation between the water surface and the glazing.

A summary of the process conditions, typical for August, is tabulated in Table B-1. These conditions are typical of the operation only since the output from day to day depends upon the amount of solar insolation received. A slightly higher output at a higher brine temperature would be expected in July. Conversely, lower operating temperatures and output would be expected during the remaining months of the year with a minimum occurring during December and January, when the amount of solar insolation captured by the still is at a minimum.

SOLAR COLLECTOR SELECTION

The most complete information on the amount of total radiation received in Southern California is available from the U. S. Weather Bureau in Los Angeles. Therefore, the monthly average of solar radiation received in the Los Angeles area during a ten-year period was used as a basis for determining the insolation available at a site in the San Diego area. Cloudless day radiation was calculated from the following relationship:

$$Q = Q_0 (a + bS) \quad (1)$$

where Q = Quantity of solar energy received on a unit area of horizontal plane at the earth's surface per unit of time.

TABLE B-1

SUMMARY OF PROCESS CONDITIONS^A
(3°F TERMINAL TEMPERATURE DIFFERENCE)

| | |
|---|-------------|
| NUMBER OF STAGES | 20 |
| MAXIMUM SEA WATER TEMPERATURE, °F | 140 |
| SEA WATER TEMPERATURE TO SOLAR HEATER, °F | 132 |
| TEMPERATURE RISE IN SOLAR HEATER, °F | 8 |
| BLOWDOWN TEMPERATURE °F | 80 |
| PRODUCT TEMPERATURE, °F | 78 |
| SEA WATER FLOW, GPM | 174,000 |
| PRODUCT, GPM | 10,200 |
| SEA WATER SALT CONCENTRATION, PPM | 33,600 |
| BLOWDOWN SALT CONCENTRATION, PPM | 35,700 |
| VELOCITY OF SEA WATER IN TUBES, FT/SEC | 6 |
| SOLAR COLLECTOR AREA, ACRES | 595 |
| NUMBER OF LAYERS OF GLAZING | 5 |
| SOLAR COLLECTOR HEAT DUTY, BTU/HR X 10 ⁻⁶ | 680 |
| SOLAR COLLECTOR NET HEAT GAIN, BTU/(FT ²) (DAY) | 630 |
| SEA WATER VELOCITY IN COLLECTOR, FT/SEC | 0.06 TO 0.1 |
| RESIDENCE TIME OF SEA WATER IN COLLECTOR, HOURS | 36 |

A) TYPICAL FOR OPERATION DURING AUGUST.

Q_0 = Cloudless day radiation. Quantity of solar energy received on a unit area of horizontal plane at the earth's surface per unit of time during cloudless days.

S = Number of hours of sunshine instrumentally recorded divided by the number of hours of possible sunshine.

a, b = Constants.

Based on the cloudless day radiation calculated for Los Angeles, the expected radiation received in San Diego was calculated using sunshine data published by the Weather Bureau in San Diego. The mean solar radiation received in Los Angeles varies from a low of 856 Btu/(Ft²)(Day) in December to a high of 2,370 in July. Corresponding figures calculated for San Diego are 843 to 2,155, respectively.

Since the angle of incidence of radiation changes continuously with relation to a horizontal surface, it is necessary to determine the amount of heat captured by a solar collector on an hourly basis. The data of L6f (80) in which he presented the fraction of total daily radiation received on a horizontal surface each hour by month was used in this study.

It was determined that the effect of the latitude difference between Los Angeles and San Diego on the insolation received amounted to a negligible correction during the summer months; however, correction of several percent was indicated for

the six winter months from October through March. Appropriate corrections were applied to the insolation data to obtain the final calculated values for San Diego. The result of these calculations are shown graphically in Figure B-2 for the months of August through December. The other months have curves with a similar shape.

The solar energy received on a horizontal surface as shown in Figure B-2 is composed of direct and diffuse radiation. The Weather Bureau measurements were made with an Eppley pyrhelimeter (81,82), which measured the total radiation falling on a horizontal surface. Since the incident angle of diffuse radiation does not vary with time of day and year as it does with direct radiation, it was necessary to determine each component separately.

Several references were found which gave an estimate of the percent of diffuse radiation (80,83,84,85). Typical values for three solar times in July are itemized below. Values used in this study for each month by hourly solar time can be derived from data presented in Table B-2.

| <u>Time from Solar Noon Hours</u> | <u>Diffuse Radiation Percent</u> |
|-----------------------------------|----------------------------------|
| 0.5 | 17½ |
| 2.5 | 18 |
| 4.5 | 20½ |

With the total insolation determined and the percent of diffuse radiation established, it was possible to calculate the quantity of direct and diffuse solar radiation available on a monthly average basis for each hour of solar time. The results

FIGURE B-2

AVERAGE HOURLY SOLAR RADIATION ON A
HORIZONTAL SURFACE AUG. THRU DEC.

(SOUTHERN CALIFORNIA COSTAL AREA)

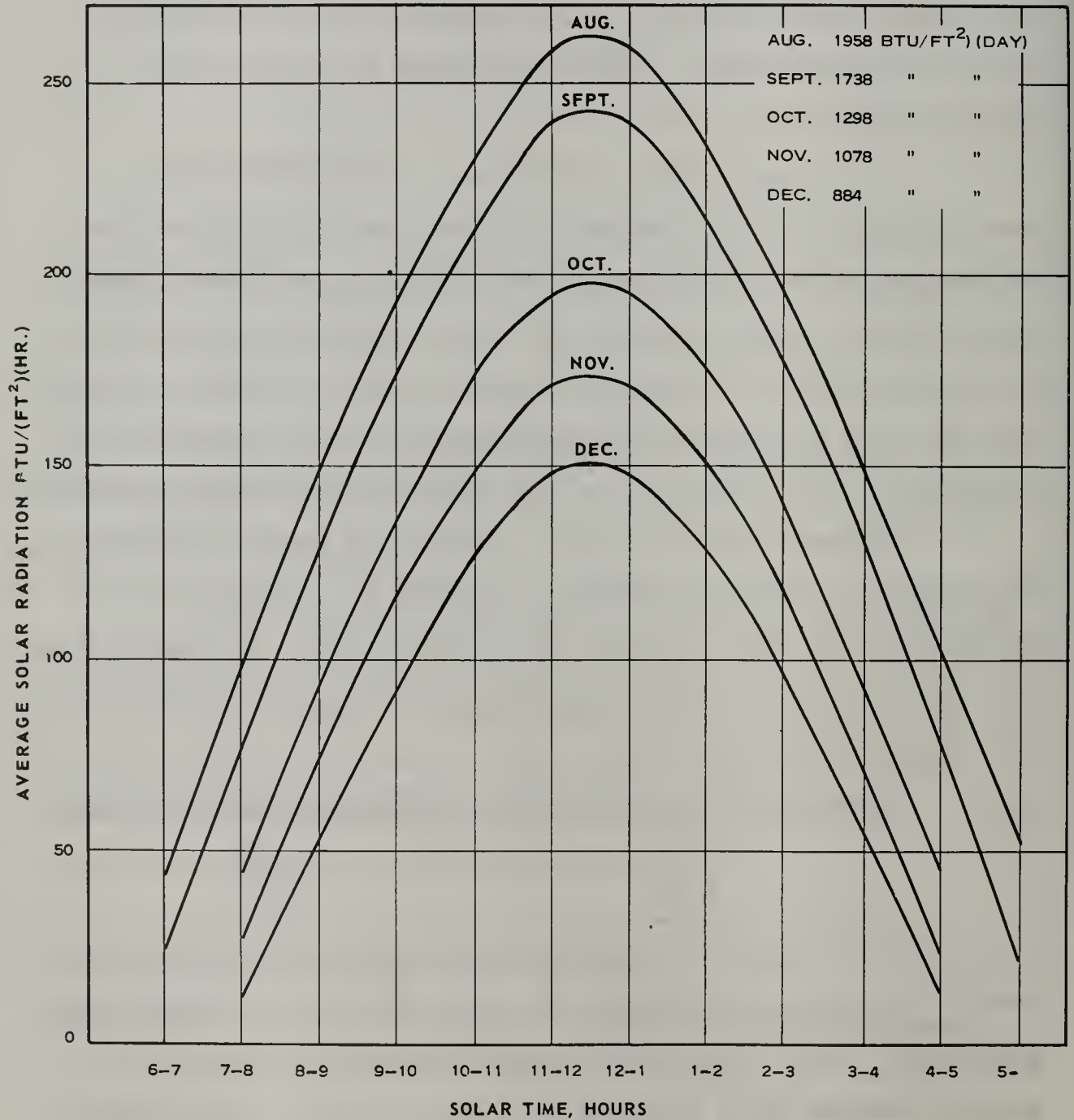


TABLE B-2
HOURLY SUMMARY OF DIRECT AND DIFFUSE RADIATION
(MONTHLY AVERAGE BASIS)

| MONTH | | SOLAR TIME | | | | | | TOTAL BTU FT ² DAY |
|-------|----------------|--|-------|------|-----|-----|-----|-------------------------------------|
| | | 11-12 | 10-11 | 9-10 | 8-9 | 7-8 | 6-7 | |
| | | 12-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | |
| | | INSOLATION, BTU/ (FT ²) (HR) | | | | | | |
| JAN | I _B | 42 | 37 | 29 | 20 | 9 | - | 274 |
| | I _D | 107 | 94 | 71 | 38 | 9 | - | 838 |
| | I _T | 149 | 131 | 100 | 58 | 18 | - | 912 |
| FEB | I _B | 53 | 48 | 39 | 27 | 16 | - | 366 |
| | I _D | 142 | 127 | 99 | 83 | 24 | - | 910 |
| | I _T | 195 | 175 | 138 | 90 | 40 | - | 1276 |
| MAR | I _B | 43 | 39 | 33 | 25 | 17 | 8 | 326 |
| | I _D | 197 | 178 | 144 | 99 | 51 | 9 | 1358 |
| | I _T | 240 | 217 | 177 | 124 | 88 | 15 | 1682 |
| APR | I _B | 40 | 38 | 32 | 25 | 19 | 9 | 326 |
| | I _D | 193 | 171 | 147 | 109 | 63 | 24 | 1414 |
| | I _T | 233 | 209 | 179 | 134 | 82 | 33 | 1740 |
| MAY | I _B | 46 | 41 | 35 | 27 | 19 | 10 | 356 |
| | I _D | 216 | 192 | 159 | 120 | 76 | 29 | 1584 |
| | I _T | 262 | 233 | 194 | 147 | 95 | 39 | 1940 |
| JUN | I _B | 44 | 40 | 35 | 29 | 22 | 16 | 372 |
| | I _D | 206 | 190 | 161 | 127 | 89 | 49 | 1648 |
| | I _T | 252 | 230 | 196 | 156 | 111 | 65 | 2020 |
| JUL | I _B | 45 | 41 | 37 | 31 | 26 | 19 | 398 |
| | I _D | 215 | 196 | 170 | 139 | 99 | 59 | 1756 |
| | I _T | 260 | 237 | 209 | 170 | 125 | 78 | 2154 |
| AUG | I _B | 45 | 40 | 35 | 28 | 21 | 12 | 362 |
| | I _D | 215 | 191 | 161 | 121 | 77 | 33 | 1596 |
| | I _T | 260 | 231 | 196 | 149 | 98 | 45 | 1958 |
| SEP | I _B | 43 | 39 | 33 | 26 | 19 | 8 | 336 |
| | I _D | 197 | 175 | 146 | 106 | 59 | 18 | 1402 |
| | I _T | 240 | 214 | 179 | 132 | 78 | 26 | 1738 |
| OCT | I _B | 35 | 33 | 26 | 21 | 12 | - | 254 |
| | I _D | 160 | 145 | 113 | 71 | 33 | - | 1044 |
| | I _T | 195 | 178 | 139 | 92 | 45 | - | 1298 |
| NOV | I _B | 47 | 42 | 35 | 23 | 13 | - | 320 |
| | I _D | 124 | 108 | 84 | 47 | 15 | - | 758 |
| | I _T | 171 | 151 | 119 | 70 | 28 | - | 1078 |
| DEC | I _B | 41 | 37 | 28 | 20 | 7 | - | 266 |
| | I _D | 107 | 93 | 67 | 35 | 7 | - | 618 |
| | I _T | 148 | 130 | 95 | 55 | 14 | - | 884 |

A) I_D DIFFUSE INSOLATION

B) I_D DIRECT INSOLATION

C) I_T TOTAL INSOLATION

are shown in Table B-2. The next step was to determine how much of this available energy could be captured by a solar heat collector.

Preliminary calculations of the transmission of solar radiation through multiple layers of glazing (glass and plastics) indicated the superiority of Tedlar* over the others; consequently, the detailed calculations were made assuming a Tedlar glazing. The calculations were based on the work by Hottel (86). The transmittance of the surface was calculated from the following equation developed by Hottel:

$$\tau_n = \frac{1-r}{1 + (2n-1) r}$$

where τ_n = Overall transmittance of n layers of nonabsorbing glazing.

r = Surface reflectivity of glazing.

n = Number of layers of glazing material.

The transmittance of a single layer of Tedlar as a function of the incident angle of the sun was obtained from a chart presented by Edlin (87). This measured value of transmittance is the net amount of energy transmitted by the glazing, taking into account both reflection and absorption losses. With the single layer transmittance known, the transmittance of multiple layers was calculated in accordance with Hottel's equation.

The absorptivity of a blackened surface is a function of the angle of incidence, and was based on data presented by Hottel (86) and Yellott (88). The product of the transmittance and

*duPont registered trademark.

absorptivity of the glazing as a function of the number of layers of glazing and incidence angle is shown in Table B-3 for three, four, and five layers of Tedlar glazing. Figure B-3 shows the transmittance-absorption variation with the angle of incidence for one to seven layers of Tedlar glazing. Values read from Figure B-3 were used to calculate the direct and diffuse solar radiation captured by the solar heat collector. The angle of incidence is a function of time of day and year for the direct radiation. Appropriate values were used to read the transmittance-absorption product from Figure B-3. The product for the diffuse component of the radiation is a value corresponding to an angle of incidence of 58° . (80,89).

The total insolation captured by five layers of Tedlar glazing was calculated to be $1,439 \text{ Btu}/(\text{Ft}^2)(\text{Day})$ in July, and 465 in December. Intermediate values were determined for the remainder of the months.

The heat that is transmitted through the glazing surface and absorbed by the collector is available for heating the brine. The useful amount depends on the fraction that is not lost to the atmosphere or ground.

The calculation of heat losses from solar collectors has been treated by several investigators (86,90,91,92). In this study the equation developed by Hottel (86) which neglects the transparency of the glazing in the infrared portion of the spectrum was used. The relationship, although somewhat complicated, can be

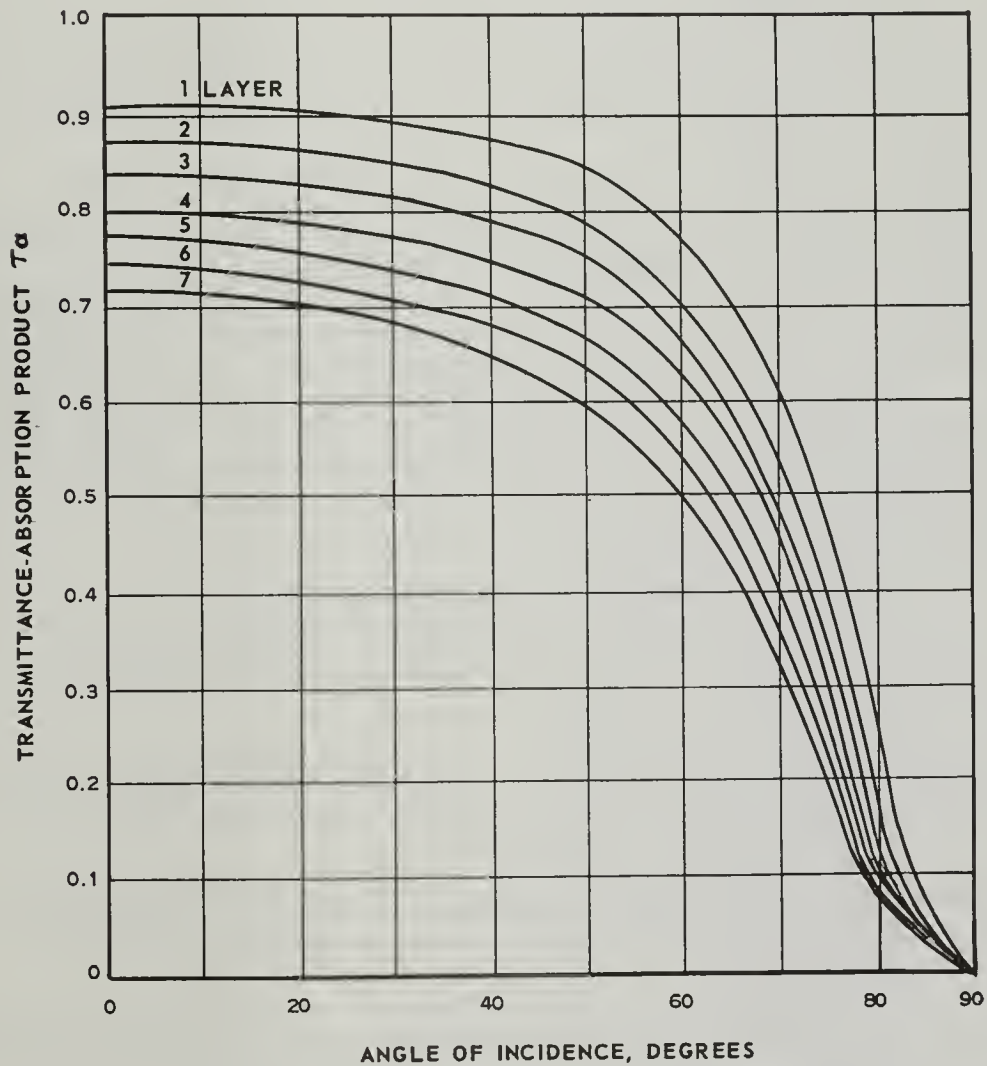
TABLE B-3
TRANSMITTANCE-ABSORPTION PRODUCT FOR TEOLAR AND
BLACKENED COLLECTOR BOTTOM

| <u>NUMBER OF LAYERS</u> | <u>INCIDENCE ANGLE DEGREES</u> | <u>TRANSMITTANCE</u> | <u>ABSORPTIVITY OF BOTTOM</u> | <u>PRODUCT^A</u> |
|---------------------------------|--|----------------------|-----------------------------------|----------------------------|
| 3 | 0 | 0.878 | 0.960 | 0.833 |
| | 20 | 0.871 | 0.958 | 0.826 |
| | 40 | 0.832 | 0.939 | 0.773 |
| | 60 | 0.755 | 0.880 | 0.658 |
| | 80 | 0.182 | 0.657 | 0.118 |
| 4 | 0 | 0.840 | 0.960 | 0.798 |
| | 20 | 0.836 | 0.958 | 0.793 |
| | 40 | 0.788 | 0.939 | 0.733 |
| | 60 | 0.703 | 0.880 | 0.612 |
| | 80 | 0.143 | 0.657 | 0.093 |
| 5 | 0 | 0.810 | 0.960 | 0.770 |
| | 20 | 0.803 | 0.958 | 0.762 |
| | 40 | 0.749 | 0.939 | 0.696 |
| | 60 | 0.659 | 0.880 | 0.574 |
| | 80 | 0.119 | 0.657 | 0.077 |

A) REDUCED ONE PERCENT FOR DIRT ON GLAZING SURFACE.

FIGURE B-3

TRANSMITTANCE-ABSORPTION PRODUCT FOR TEDLAR GLAZING
AND BLACK BOTTOM SURFACE WITH RESPECT TO THE ANGLE OF INCIDENCE



solved directly and has been demonstrated by Hottel to give reliable values over the range commonly encountered in solar collector design. The equation is as follows:

$$q_L/A = \frac{\frac{T - T_a}{n} + \frac{1}{h_w}}{C \left(\frac{T - T_a}{n + f} \right)^{\frac{1}{4}}} + \frac{\sigma (T^4 - T_a^4)}{\frac{1}{\epsilon_C} + \frac{2n + f - 1}{\epsilon_G} - n} \quad (2)$$

where q_L = Rate of heat loss through top of collector, Btu/hr.

A = Area, Ft^2 .

T = Absolute temperature of the brine, $^{\circ}\text{R}$.

T_a = Absolute temperature of the outer air, $^{\circ}\text{R}$.

n = One less than the total number of glazing surfaces
(one layer of glazing floating on water was not considered as contributing to heat retention except as it affects C .)

C = Constant (Figure 15 Reference 86).

f = Effective thermal resistance of outer glazing relative to others.

h_w = Forced convection coefficient due to wind on top plate, $\text{Btu}/(\text{Ft}^2)(\text{Hr})(^{\circ}\text{F})$.

σ = Stefan-Boltzmann constant $0.173 \times 10^{-8} \text{ Btu}/(\text{Ft}^2)(\text{Hr})(^{\circ}\text{F}^4)$.

ϵ_C = Emissivity and absorptivity of blackened collector.

ϵ_G = Emissivity and absorptivity of glazing.

Calculations were based on an average wind velocity of 6.4 miles per hour, which is typical for the San Diego area. The solution of the equation for four, five, and six layers of Tedlar glazing at three brine temperatures (100, 125, and 150°) and two ambient temperatures (55° and 70°) is presented in Table B-4. Ground losses of one $\text{Btu}/(\text{Ft}^2)(\text{Day})(^\circ\text{F})$ were based on the results obtained in the deep basin still (93) operated by the Battelle Memorial Institute for the Office of Saline Water in Florida.

Since heat losses are affected by change in ambient temperature, equation 2 was solved for several assumed ambient temperatures between 55° and 70°, which is a typical temperature range for the area. As is indicated in Table B-4, approximately a 6 $\text{Btu}/(\text{Ft}^2)(\text{Hr})$ increase in the heat loss is encountered when the ambient temperature changes from 70° to 55°F. Consideration of ambient temperature changes were taken into account in determining the net heat gain by the solar heat collector.

The net heat gain is the difference between the heat captured from the available solar radiation and the sum of the heat lost to the atmosphere and ground. Figure B-4 summarizes the net heat gain by month for assumed collector temperatures from 100° to 150°F. The variation in the net heat gain with time of year is shown in Figure B-5. It can be seen from Figure B-5 that the net heat gain varies considerably with time of year; in addition, the curves are not smooth. The exact shape of the curves is largely dependent on meteorological condition. The deviation from a smooth

TABLE B-4

Solution of Equation 2
(Heat Loss in Btu/(Ft²)(Day))

| No. Layers | Brine Temp °F | Ambient Temp °F | 1st Term ^a Eq. 2 | 2nd Term ^b Eq. 2 | Total Atmos. Loss | Total ^c Ground Loss | Total Heat Loss |
|---------------|---------------------|-----------------------|--------------------------------|--------------------------------|-------------------------|--------------------------------------|--------------------|
| 4 | 100 | 55 | 5.32 | 12.72 | 434 | 45 | 479 |
| | 100 | 70 | 3.22 | 9.07 | 295 | 30 | 325 |
| | 125 | 55 | 9.22 | 21.8 | 745 | 70 | 815 |
| | 125 | 70 | 6.82 | 18.14 | 598 | 55 | 653 |
| | 150 | 55 | 13.40 | 31.3 | 1072 | 95 | 1167 |
| | 150 | 70 | 10.87 | 27.7 | 925 | 80 | 1005 |
| 5 | 100 | 55 | 3.80 | 9.85 | 327 | 45 | 372 |
| | 100 | 70 | 2.30 | 7.04 | 224 | 30 | 254 |
| | 125 | 55 | 6.58 | 16.9 | 564 | 70 | 634 |
| | 125 | 70 | 4.87 | 14.1 | 456 | 55 | 511 |
| | 150 | 55 | 9.59 | 24.3 | 814 | 95 | 909 |
| | 150 | 70 | 7.76 | 21.5 | 700 | 80 | 780 |
| 6 | 100 | 55 | 2.91 | 8.06 | 263 | 45 | 308 |
| | 100 | 70 | 1.76 | 5.75 | 181 | 30 | 211 |
| | 125 | 55 | 5.02 | 13.8 | 452 | 70 | 522 |
| | 125 | 70 | 3.73 | 11.5 | 366 | 55 | 421 |
| | 150 | 55 | 7.35 | 19.8 | 652 | 95 | 747 |
| | 150 | 70 | 5.95 | 17.5 | 586 | 80 | 666 |

a) Where $c = 0.195$

n = One less than the number of layers

$f = 0.48$

$h_w = 2.95 \text{ Btu}/(\text{Ft}^2)(\text{Hr})(^\circ\text{F})$

b) Where $\epsilon_G, \epsilon_g = 0.95$
 $\sigma = 0.173 \times 10^{-8} \text{ Btu}/(\text{Ft}^2)(\text{Hr})(^\circ\text{R})^4$

c) Based on a loss of one Btu/(Ft²)(Day)(°F)

FIGURE B-4

NET HEAT GAIN FOR FIVE LAYERS OF TEDLAR GLAZING

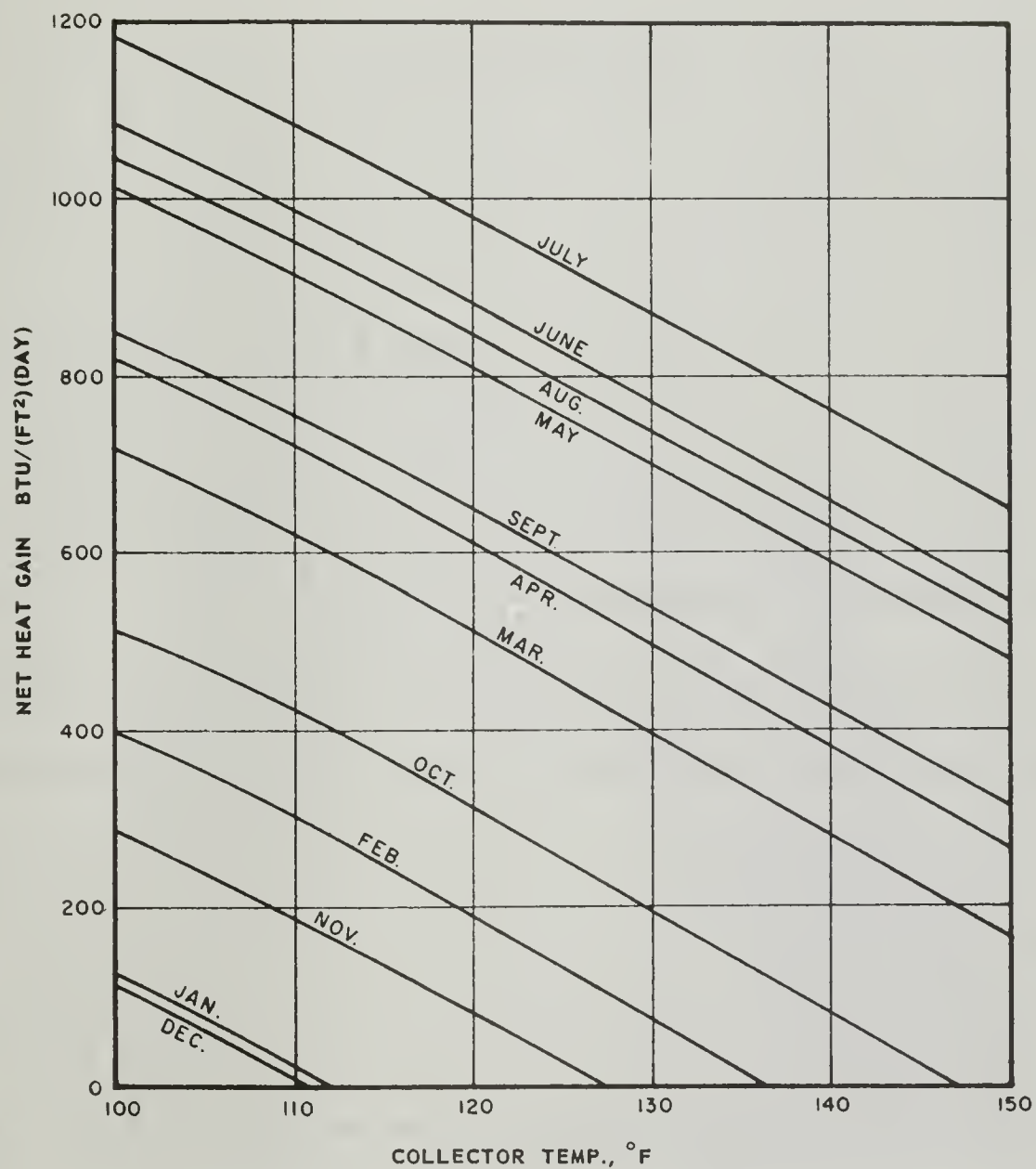
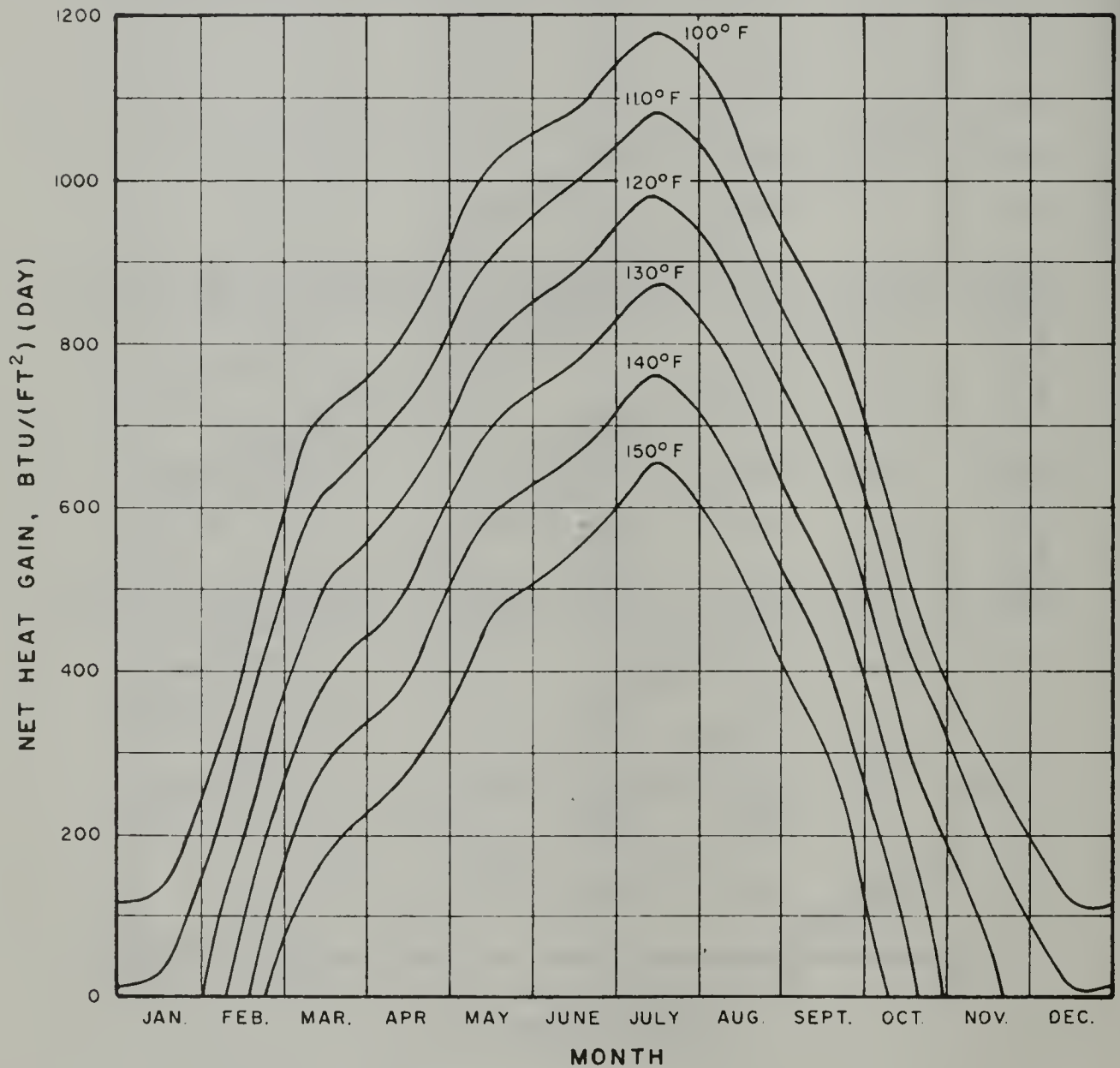


FIGURE B-5

VARIATION IN NET HEAT GAIN FOR FIVE
LAYERS OF TEDLAR GLAZING BY MONTH



curve during the spring months can be explained by the variation in the cloud covering during that time of year along the Southern California Coast.

SOLAR ENERGY COST

A preliminary calculation indicated that a solar collector area of approximately 25 million square feet would be required to capture sufficient heat to operate the multistage flash evaporator shown on Figure B-1. Since a large number of collector units would be required, an estimate of installing 1,000 units containing 24 million square feet of collector surface was made. With such an estimate the cost per unit area and the amortized cost per unit area could be determined. For a variation of no more than ten percent in the collector area the unit cost would remain the same. In this way, the optimization could be made without the necessity of making separate estimates of each assumed collector installation. Table B-5 lists the items of the solar collector and the installed cost of each with the exception of the plastic bottom covering and the glazing which are treated separately. Table B-6 shows the cost of the polyethylene bottom covering. The installed costs of the Tedlar glazing for two to seven layers, including the heat-sealing cost and installation charges, are given in Table B-7. The summary of the total daily operating cost for the solar collector is given in Table B-8.

Before the estimated cost of water from a multistage flash evaporator utilizing solar heated brine could be made, an estimate

TABLE B-5

Installed Cost of Solar Collector^a
(1000 Units 48' x 500')

| | Installed Cost Dollars | Estimated Life Years | Capital Cost \$/Unit | Amortized ^b Cost ¢/(Unit)(Day) |
|---|------------------------------|----------------------------|----------------------------|---|
| Excavation | 280,000 | 48 | 280 | 5.50 |
| Concrete and Paint ^c | 1,370,000 | 48 | 1,370 | 26.93 |
| Plastic Inserts and Glazing Holddown | 200,000 | 8 | 200 | 12.38 |
| Buggies ^d | 60,000 | 24 | 60 | 1.64 |
| Piping ^e | <u>100,000</u> | 24 | 100 | <u>2.73</u> |
| Total | 2,010,000 | | | 49.18 |

- a) Does not include plastic ground cover or glazing.
b) Money at 4% per annum.
c) Amortized over plant life of 48 years, annual painting is part of operating expense.
d) Required to span collector for washing glazing and general maintenance work.
e) Fresh water system for washing the glazing.

TABLE B-6

Cost of Bottom Covering^a

| | Collector ^b |
|--------------------------------|------------------------|
| Material Cost ^c | \$ 600 |
| Heat Sealing Cost ^d | 40 |
| Installation Cost ^e | <u>700</u> |
| Total | \$1,340 |
| Unit Cost | 5.58¢/Ft ² |
| Amortized Cost ^f | 82.92¢/(Unit)(Day) |

- a) Blackened polyethylene.
b) One collector unit is 48 ft. x 500 ft.
c) 10 mil polyethylene, \$0.50 per lb.
d) 2000 lineal feet at \$0.02/ft.
e) Includes cost of sealing bottom to the plastic inserts (500 inserts per collector).
f) 8-year life, 4% per annum, equivalent to 14.853% per annum.

TABLE B-7
Installed Cost of Tedlar Glazing

| <u>No. Layers</u> | <u>Material Cost</u> | <u>Fabri- cation Cost</u> | <u>Instal- lation Cost</u> | <u>Total Fabricated Cost</u> | <u>Amortized^a Cost ¢/(Unit)(Day)</u> |
|-----------------------|--------------------------|-----------------------------------|------------------------------------|--------------------------------------|---|
| 2 | \$ 3,597 | \$ 212 | \$ 225 | \$ 4,034 | 249.62 |
| 3 | 4,111 | 382 | 225 | 4,718 | 291.95 |
| 4 | 4,625 | 828 | 225 | 5,678 | 351.34 |
| 5 | 5,138 | 1,083 | 225 | 6,446 | 398.88 |
| 6 | 5,652 | 1,784 | 225 | 7,661 | 474.06 |
| 7 | 6,166 | 2,124 | 225 | 8,515 | 526.91 |

a) Eight years life, 4% per annum.

TABLE B-8
Total Daily Operating Cost of Solar Collectors^a
(Unit Collector 48' x 500')

| <u>No. Layers</u> | <u>Tedlar Glazing Cost ¢/(Unit)(Day)</u> | <u>Other Collector Costs ¢/(Unit)(Day)</u> | <u>Total Daily Collector Cost</u> | |
|-----------------------|--|--|-----------------------------------|-------------------------|
| | | | <u>\$/ (Unit)</u> | <u>¢/Ft²</u> |
| 2 | 249.62 | 203.03 ^b | 4.53 | 0.0189 |
| 3 | 291.95 | 203.03 | 4.95 | 0.0206 |
| 4 | 351.34 | 203.03 | 5.54 | 0.0231 |
| 5 | 398.88 | 203.03 | 6.02 | 0.0251 |
| 6 | 474.06 | 203.03 | 6.77 | 0.0282 |
| 7 | 526.91 | 203.03 | 7.30 | 0.0304 |

a) Money at 4% per annum.

b) 49.18 from Table 5; 82.92 from Table 6, plus 45.93 for real estate and 25.0 for operation and maintenance labor.

of the cost of the recovered energy was required. This estimated cost of the collected solar energy was determined in cents per million Btu. This information is summarized in Table B-9 for three to seven layers of glazing and six assumed brine temperatures between 100° and 150°. The next heat available for each selected condition is also listed in Table B-9.

An examination of Table B-9 will reveal that at constant temperature, for some of the conditions presented, the quantity of heat captured actually decreases with an increase in the number of glazing layers. See, for example, 110°F. brine temperature in July, where the maximum heat captured is with five layers of glazing. This simply means that the incremental heat loss due to reflection and absorption by the added layer of glazing, is greater than the heat saved as a result of one more layer of glazing acting as an additional heat insulator.

The solar heat cost in cents per million Btu is graphically presented in Figure B-6. The domains of glazing layers are indicated on the chart. At 3°F. terminal temperature difference the brine temperature for minimum water cost is between 130° and 150°F. As can be seen from Figure B-6, during the six months from April through September, the optimum falls within the domain of five layers of glazing. Since the majority of the plant output occurs during this period, the optimization will be heavily weighed in favor of five layers of glazing.

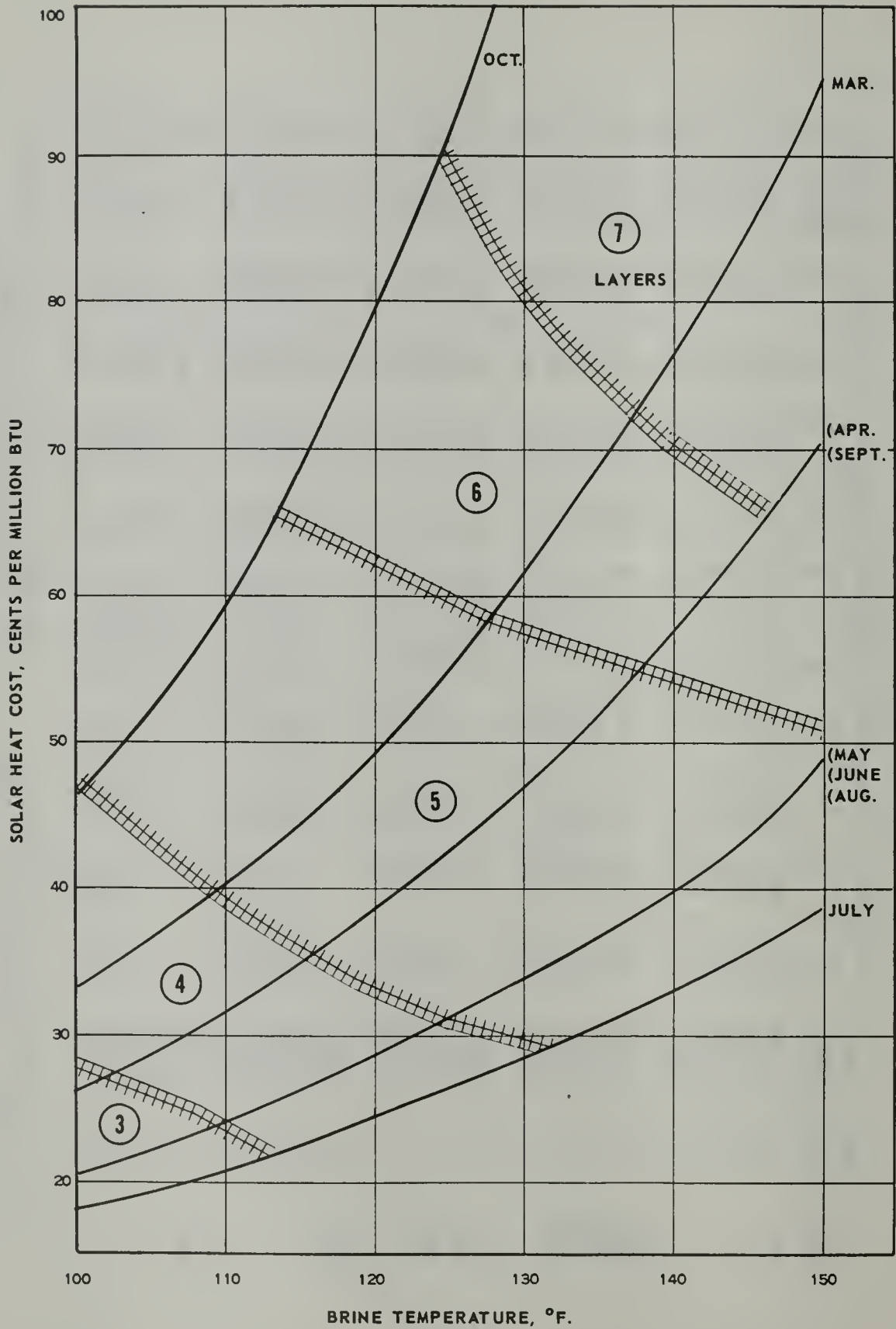
Cost of Collected Solar Energy

| Month | Total Layers | Amort. Cost ^a | Brine Temperature | | | | | | | | | | | |
|---------------------------------|--------------|--------------------------|-------------------|------|--|-------|------|-----|-------|-----|------|-------|------|------|
| | | | 150°F | | | 140°F | | | 130°F | | | 120°F | | |
| | | | b | c | | b | c | | b | c | | b | c | |
| July | 3 | 0.0206 | 166 | 124. | | 370 | 55.7 | 575 | 35.8 | 775 | 26.6 | 970 | 21.3 | 1145 |
| | 4 | 0.0231 | 515 | 44.9 | | 660 | 35.0 | 800 | 28.9 | 940 | 24.5 | 1075 | 21.5 | 1199 |
| | 5 | 0.0251 | 653 | 38.4 | | 760 | 33.0 | 870 | 28.9 | 980 | 25.6 | 1085 | 23.1 | 1180 |
| | 6 | 0.0282 | 693 | 40.7 | | 792 | 35.5 | 892 | 31.6 | 990 | 28.5 | 1075 | 26.2 | 1151 |
| | 7 | 0.0304 | 738 | 41.2 | | 815 | 37.3 | 896 | 33.9 | 973 | 31.2 | 1048 | 29.0 | 1118 |
| May June and Aug | 3 | 0.0206 | 32 | 644. | | 225 | 91.5 | 435 | 47.4 | 640 | 32.2 | 835 | 24.7 | 1002 |
| | 4 | 0.0231 | 374 | 61.8 | | 515 | 44.9 | 658 | 35.2 | 800 | 28.9 | 935 | 24.7 | 1052 |
| | 5 | 0.0251 | 522 | 48.2 | | 630 | 39.9 | 740 | 34.0 | 850 | 29.6 | 950 | 26.4 | 1046 |
| | 6 | 0.0282 | 571 | 49.4 | | 668 | 42.2 | 765 | 36.9 | 860 | 32.8 | 950 | 29.7 | 1023 |
| | 7 | 0.0304 | 621 | 49.0 | | 700 | 43.4 | 778 | 39.1 | 855 | 35.6 | 927 | 32.8 | 998 |
| Apr and Sept ^e | 3 | 0.0206 | - | - | | - | - | 210 | 98.0 | 410 | 50.3 | 605 | 34.1 | 777 |
| | 4 | 0.0231 | 163 | 142. | | 308 | 75.0 | 450 | 51.4 | 595 | 38.8 | 730 | 31.7 | 850 |
| | 5 | 0.0251 | 318 | 79.0 | | 430 | 58.4 | 540 | 46.5 | 650 | 38.6 | 755 | 33.3 | 848 |
| | 6 | 0.0282 | 370 | 76.2 | | 468 | 60.2 | 568 | 49.7 | 665 | 42.4 | 750 | 37.6 | 829 |
| | 7 | 0.0304 | 435 | 69.9 | | 515 | 59.0 | 594 | 51.2 | 674 | 45.2 | 750 | 40.5 | 814 |
| Mar | 3 | 0.0206 | - | - | | - | - | - | - | 190 | 108. | 385 | 53.5 | 567 |
| | 4 | 0.0231 | - | - | | 145 | 159. | 285 | 81.1 | 425 | 54.4 | 565 | 40.9 | 693 |
| | 5 | 0.0251 | 174 | 144. | | 285 | 88.1 | 400 | 62.8 | 515 | 48.8 | 622 | 40.4 | 720 |
| | 6 | 0.0282 | 268 | 105. | | 362 | 77.8 | 460 | 61.3 | 555 | 50.8 | 640 | 44.1 | 720 |
| | 7 | 0.0304 | 321 | 94.7 | | 400 | 76.0 | 478 | 63.5 | 555 | 54.7 | 630 | 48.2 | 698 |
| Oct | 3 | 0.0206 | - | - | | - | - | - | - | - | - | 165 | 125. | 375 |
| | 4 | 0.0231 | - | - | | - | - | 90 | 257. | 235 | 98.3 | 380 | 61.8 | 493 |
| | 5 | 0.0251 | - | - | | 85 | 296. | 200 | 126. | 315 | 79.7 | 424 | 59.3 | 512 |
| | 6 | 0.0282 | 54 | 522. | | 155 | 182. | 255 | 111. | 355 | 79.5 | 440 | 64.1 | 516 |
| | 7 | 0.0304 | 117 | 260. | | 195 | 156. | 275 | 110. | 356 | 85.3 | 430 | 70.7 | 496 |

- a) Amortized Cost in $\$/(\text{Ft}^2)(\text{Day})$ c) Cost of Collected Solar Heat $\$/10^6$ Btu.
b) Net Heat Available Btu/ $(\text{Ft}^2)(\text{Day})$ d) August Net Heat Values Used.
e) September Net Heat Values Used.

FIGURE B-6

DOMAINS OF GLAZING LAYERS FOR SOLAR HEAT COST



EVAPORATOR COST

Data developed in a previous study (79) of evaporator economics was largely used in this analysis. A summary of the multistage flash evaporator heat and flow conditions for several terminal temperature differences is presented in Table B-10. The estimated capital costs are presented in Table B-11.

The variation in the evaporator output with brine temperature is presented in Figure B-7 and the variation in the evaporator heat requirement with brine temperature is presented in Figure B-8. The summary of the flash evaporator operating costs is presented in Table B-12.

WATER COST

To the evaporator cost, must be added the cost of collecting the energy in the solar heat collector. The variation in the water cost for the time of year and brine temperature is shown graphically in Figure B-9 for a 3°F. terminal temperature difference, which was established to be about optimum for this design. The cost curves shown in Figure B-9 represent all costs associated with both the evaporator and solar heat collector. The weighted average cost of water is \$1.10 per 1,000 gallons.

RECOMMENDATIONS

The ideal glazing would be a material that transmitted all of the solar energy into the collector and, at the same time, reflected the long wave reradiation from the collector. Research

TABLE B-10

Summary of Flash Evaporator Heat and Flow Conditions
for Several Terminal Temperature Differences
(20-Stage Plant)

| TTD ^a °F | Brine _b Temp. °F | Solar Heater Duty ⁻⁶ Btu/Hr x 10 | Plant Capacity ^c GPD x 10 ⁻⁶ |
|------------------------|-----------------------------------|---|---|
| 1.5 | 100 | 305 | 4.9 |
| | 110 | 365 | 7.35 |
| | 120 | 430 | 9.8 |
| | 130 | 490 | 12.25 |
| | 140 | 553 | 14.7 |
| | 150 | 612 | 17.1 |
| 3.0 | 100 | 335 | 4.9 |
| | 110 | 425 | 7.35 |
| | 120 | 510 | 9.8 |
| | 130 | 595 | 12.25 |
| | 140 | 680 | 14.7 |
| | 150 | 765 | 17.1 |
| 4.5 | 100 | 335 | 4.0 |
| | 110 | 431 | 6.0 |
| | 120 | 515 | 8.0 |
| | 130 | 585 | 10.0 |
| | 140 | 660 | 12.0 |
| | 150 | 735 | 14.0 |

- a) Stage terminal temperature difference
b) Inlet temperature to first stage
c) Capacity the same for TTD of 1.5° and 3.0° F since the number of condenser tubes is the same for each.

TABLE B-11

Flash Evaporator Capital Cost and Power Requirements
(20-Stage Plant)

| TTD ^a , °F | 1.5 | 3.0 | 4.5 |
|--------------------------------------|-----------|-----------|-----------|
| Capital Cost x 10 ⁻⁶ , \$ | 20.7 | 15.5 | 11.3 |
| Condenser Area, Ft ² | 4,150,000 | 2,620,000 | 1,580,000 |
| Pumping Horsepower ^b | 22,700 | 18,300 | 13,450 |

- a) Stage terminal temperature difference.
b) Total of all installed pumps including pump and motor efficiencies. Based on velocity of 6 ft/sec in condenser tubes for sea water pump.

FIGURE B-7

VARIATION IN FLASH EVAPORATOR OUTPUT WITH
BRINE FEED TEMPERATURE

(3°F TERMINAL TEMPERATURE DIFFERENCE)

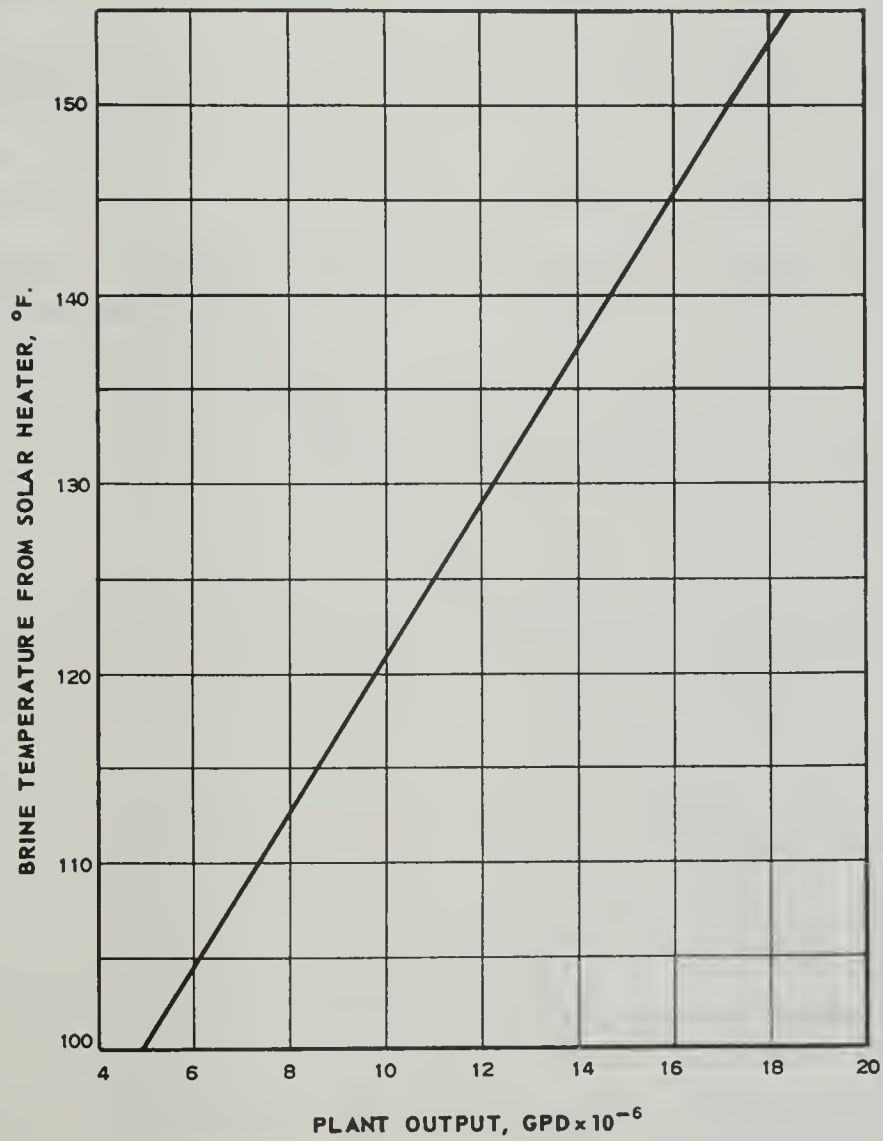


FIGURE B-8

VARIATION IN FLASH EVAPORATOR HEAT REQUIREMENTS
WITH BRINE FEED TEMPERATURE
(3°F TERMINAL TEMPERATURE DIFFERENCE)

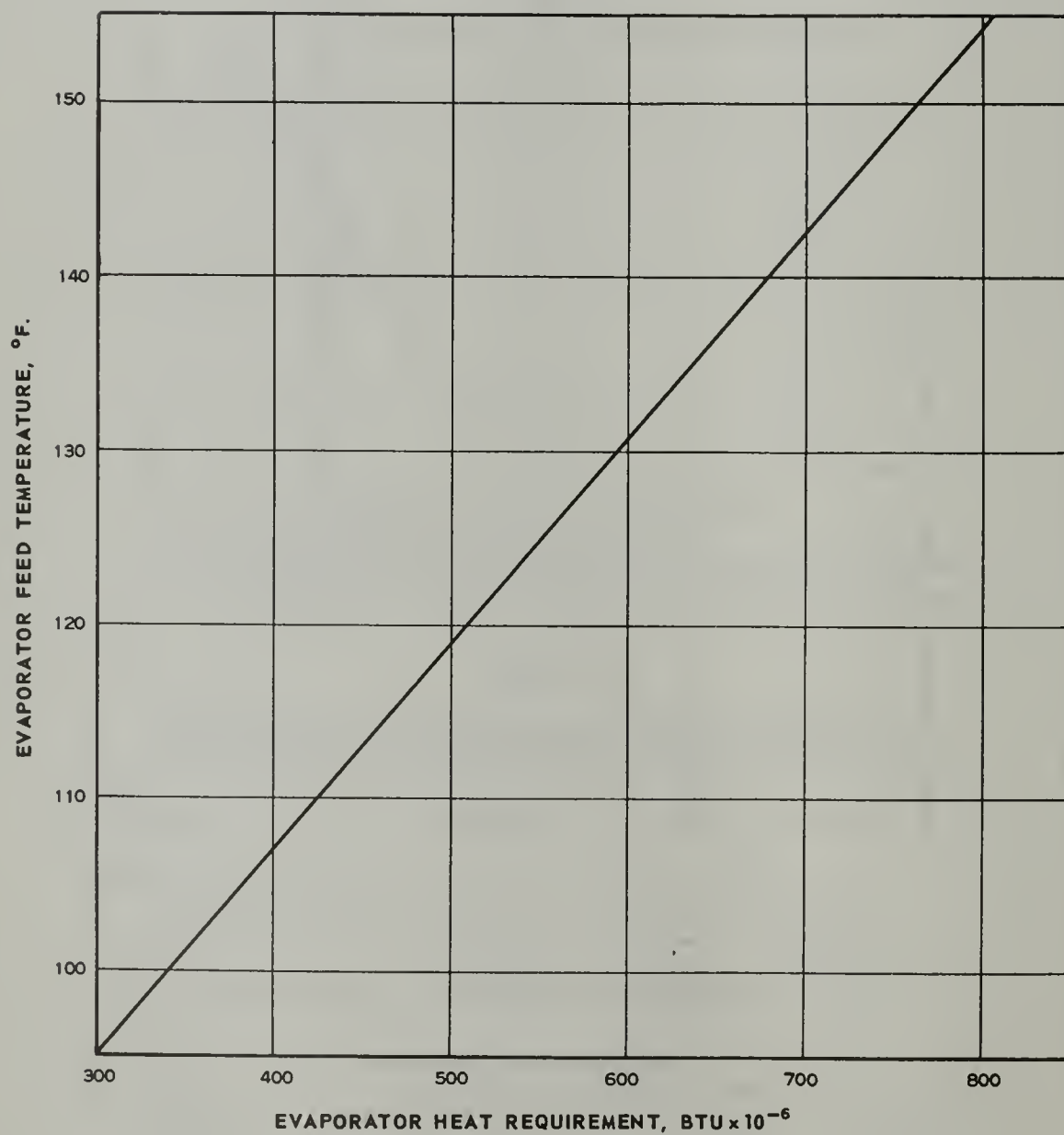
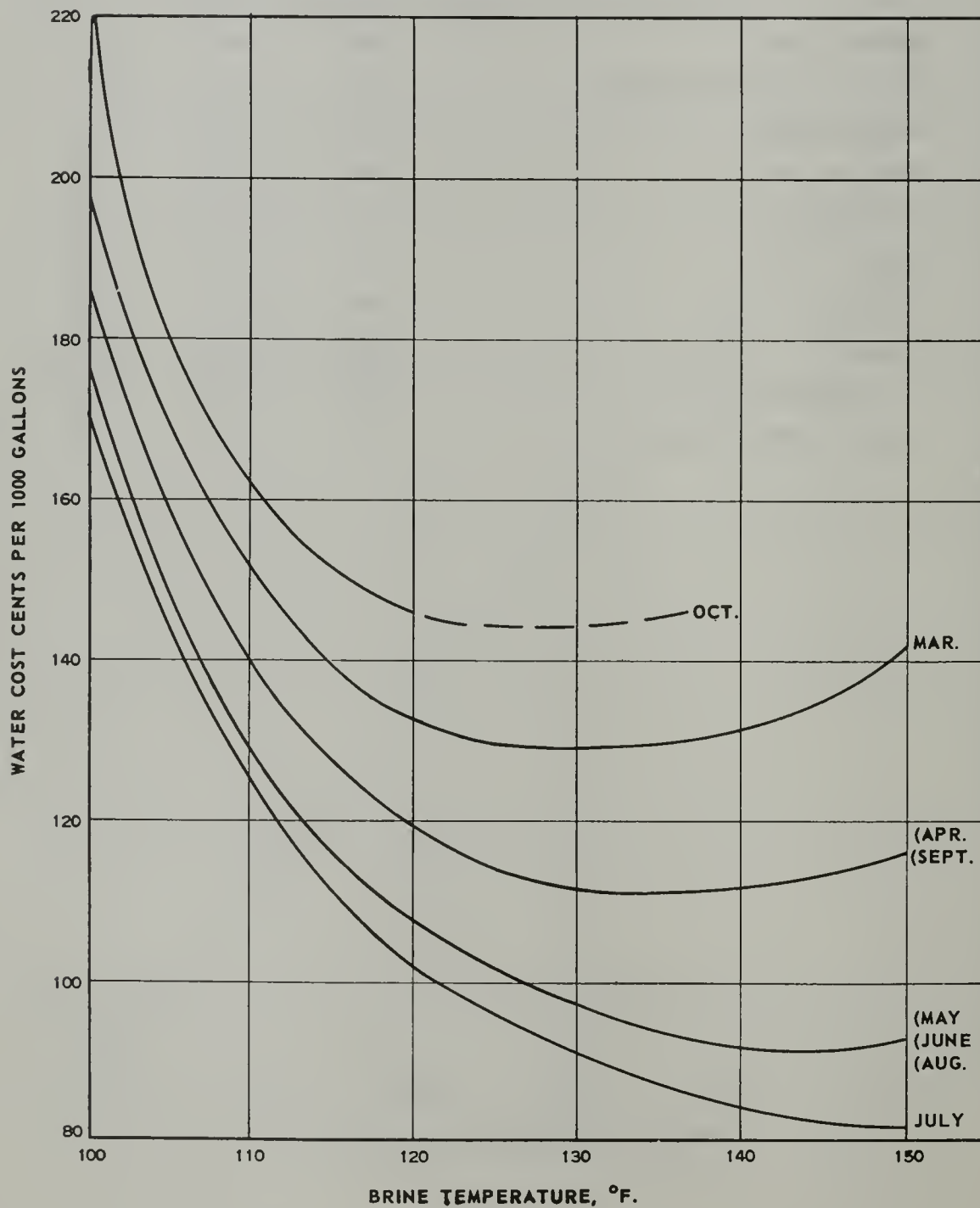


TABLE 8-12

FLASH EVAPORATOR OPERATING COSTS
(DOLLARS PER STREAM DAY)

| TTD, °F | 1.5 | 3.0 | 4.5 |
|-----------------------------------|-----------|-----------|-----------|
| ELECTRICAL ENERGY | 4410 | 3310 | 2420 |
| SUPPLIES AND MAINTENANCE MATERIAL | 175 | 88 | 70 |
| OPERATING LABOR | 191 | 191 | 191 |
| MAINTENANCE LABOR | 130 | 66 | 52 |
| PAYROLL EXTRAS | 48 | 39 | 36 |
| OVERHEAD | 43 | 43 | 43 |
| AMORTIZATION | 4152 | 3109 | 2267 |
| INSURANCE | <u>60</u> | <u>45</u> | <u>33</u> |
| EVAPORATOR TOTAL | 9208 | 6891 | 5112 |
| INTEREST ON WORKING CAPITAL | 64 | 48 | 36 |

FIGURE B-9
WATER COST VERSUS BRINE TEMPERATURE
FOR
3°F. TERMINAL TEMPERATURE DIFFERENCE



with glazing materials to improve the transmittance and, at the same time, reduce the reradiation losses could improve the economics of a solar heat collector. It is, therefore, recommended that these two avenues of investigation be considered by researchers in this field.

SUMMARY AND CONCLUSIONS

1. The economics of a combination of sea water evaporator-solar heat collector have been examined on the basis of current technology using 1960 construction costs. A multistage flash evaporator was selected for the sea water evaporator. A Tedlar covered solar heat collector was selected to heat the brine used in the evaporator.
2. Approximately 10,600 acre-feet of potable water could be produced during a ten-month operating year utilizing nearly one square mile of solar heat collector surface.
3. The total capital cost of the plant was estimated to be approximately 26 million dollars, 60 percent of which was the cost of the evaporator and its auxiliaries. The remaining 40 percent for the solar heat collector was divided into 26 percent for the glazing, 6 percent for the plastic bottom, and 8 percent for the collector installation.

4. During a ten-month operating year the average water cost for the plant was estimated to be approximately \$1.10 per thousand gallons.

5. During a ten-month operating year the solar heat collector would capture slightly more than four trillion Btu.

6. Considerable improvement in the materials used for glazing will be required before the reflection and reradiation losses can be reduced sufficiently to make this means of obtaining heat generally economically attractive.

APPENDIX C

BIBLIOGRAPHY

APPENDIX C

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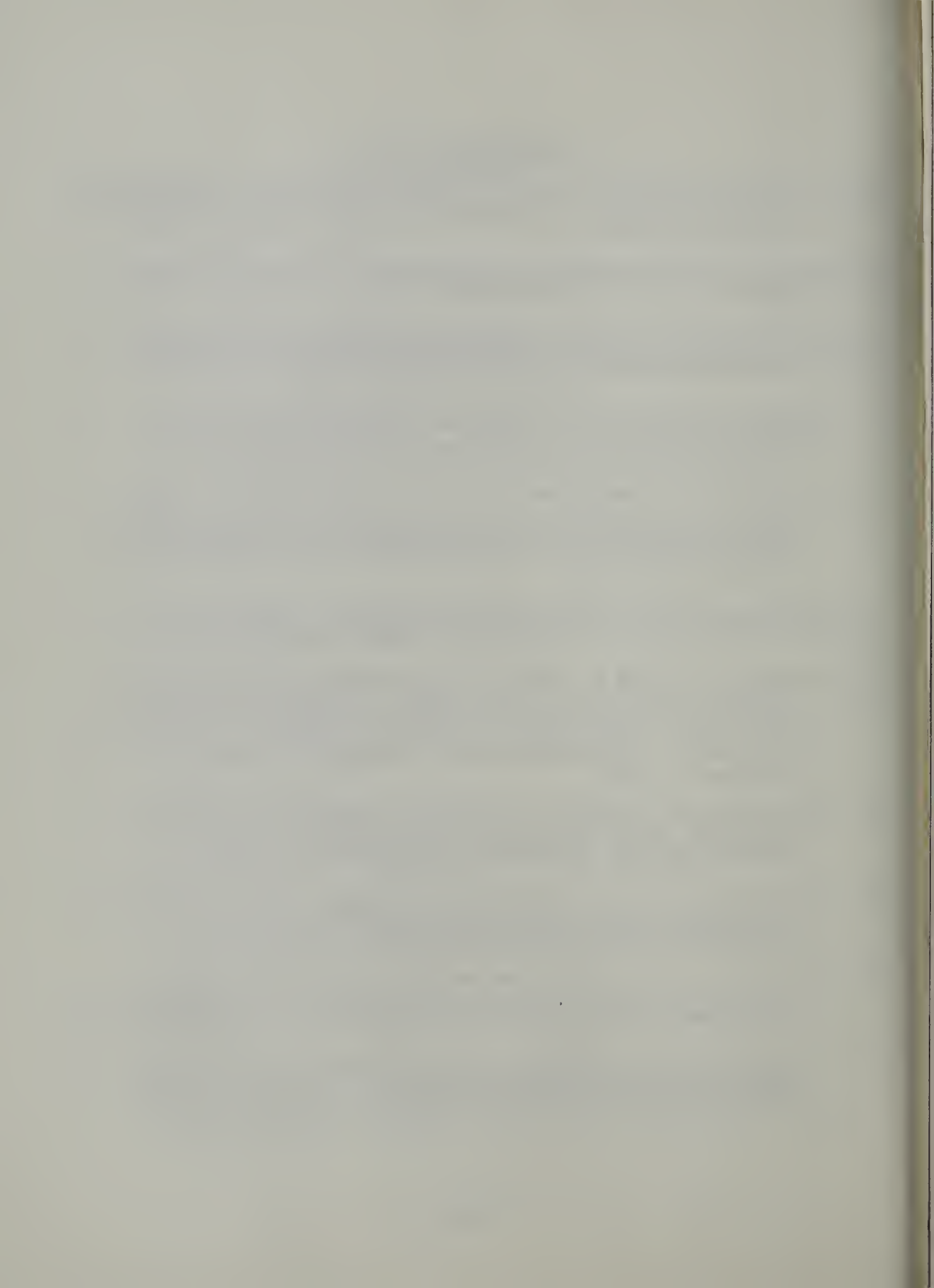
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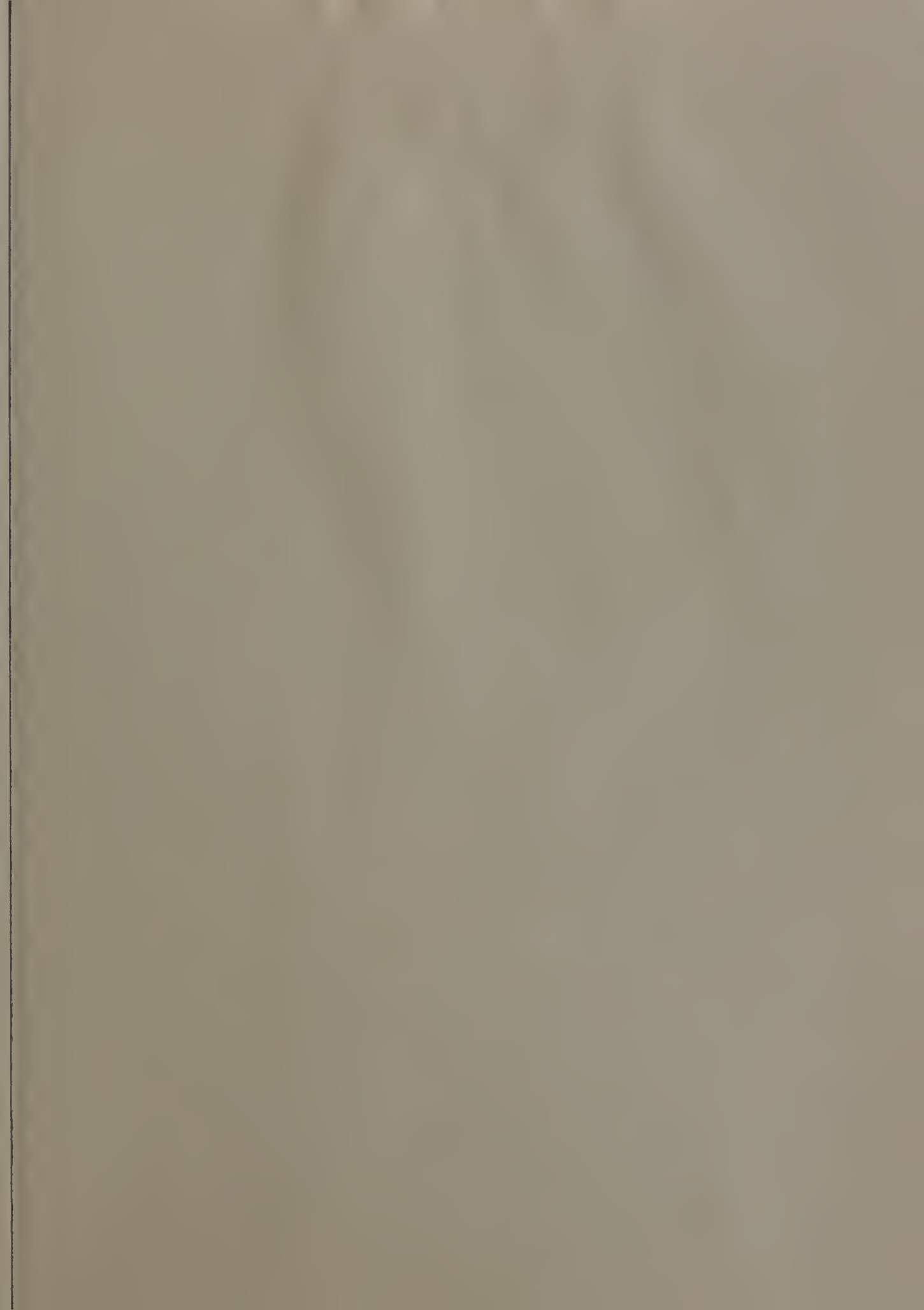
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